EnviroQual

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January 14, 1997

Richard Woodard
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Dear Rick:

I understand that the Bay Delta Process is beginning to consider water quality issues other than salinity. Since this is an area that I have been involved in since 1989 when I returned to California, I would like to be placed on the mailing list to receive announcements of the various committees meetings and minutes that your group has in connection with water quality issues in the Delta that are going to be addressed as part of Prop. 204., etc. One of my clients that caused me to move back to California in 1989 was Delta Wetlands, where I reviewed the potential water quality that would develop in several water supply reservoirs that that firm proposed to construct on Delta islands. At that time I became familiar with the water quality database on the Delta and its tributaries. Since then I have continued to review the data as it became available and have been active in a number of areas designed to try to get more appropriate review of Delta water quality issues than has been done in the past.

Several years ago I was asked by the University of California, Water Resources Center to develop a review on water supply source water quality issues as it relates to Delta water quality. This review included a review "Regulating Drinking Water Quality at the Source," Proc. University of California Water Resources Center Conference: Protecting Water Supply Water Quality at the Source, Sacramento, CA, 39pp, April (1991). Part of this paper has been published in the conference proceedings as: Lee, G.F. and Jones, R.A., "Managing Delta Algal Related Drinking Water Quality: Tastes and Odors and THM Precursors," pp. 105-121, April (1991). As part of developing this review I updated my review of the Delta water quality issues pointing out a number of areas that are only now beginning to be addressed as needing attention.

Also as part of the CA/NV American Water Works Section activities, I developed a review of the Section's Source Water Quality Committee, "Impact of the Current California Drought on Source Water Supply Water Quality," Presented at CA/NV AWWA Fall Conference, Anaheim, CA 30pp, October (1991). This review pointed to the importance of Delta water quality in influencing the use of the Delta as a domestic water supply source.

As part of the Sacramento River Watershed Toxics Control Program that was initiated about one year ago, I have tried to get this program to consider Delta water quality issues and developed a write-up discussing the importance of properly addressing these issues in evaluating the impact of constituent discharges/runoff to the Sacramento River system on "downstream" water quality. I was only partially successful in achieving this approach. Quite possibly the work that is now being done within your group would address the issues that from my perspective need to be addressed to properly manage water quality in the Delta.

Since last summer, I have been working to get the DeltaKeeper involved in real water quality issues and have obtained an expression of interest to conduct toxicity monitoring studies in the Delta to examine the aquatic life toxicity that occurs in various parts of the Delta at various times of the year. While previous studies have demonstrated that there are potential problems due to organophosphorus pesticides causing aquatic life toxicity in the Delta, these studies have not continued to be carried out due to restrictions in funding.

The DeltaKeeper studies parallel similar studies that I am conducting in Orange County with respect to Upper Newport Bay water quality in which, as planned now, we will not only be assessing the amount of toxicity to determine its significance to the beneficial uses of Upper Newport Bay and the Delta, but also to determining the origin of the constituents responsible. In the case of Upper Newport Bay, the sampling that we have done this past fall has shown that there are four pesticides in stormwater runoff to the Bay which are causing high levels of aquatic life toxicity in the runoff waters, three of which are derived primarily from structural pest control and the fourth from agricultural use.

Our studies in Newport Bay are being conducted as part of a new approach that we have developed on evaluating water quality use impairments. This approach, what we call Evaluation Monitoring, focuses the monitoring resources on assessing water quality use impairments of the receiving waters rather than measuring a suite of chemical constituents and then trying to in some way extrapolate to use impairments. By use impairments, we mean aquatic life toxicity as opposed to the measurement of potentially toxic chemicals. Similarly, rather than trying to estimate bioaccumulation based on the concentrations of constituents that are potentially bioaccumulatable, Evaluation Monitoring measures actual bioaccumulation directly through an analysis of fish tissue and then determines the source of the constituents responsible for the bioaccumulation if a problem is found. Enclosed is a write-up that I have developed on this topic that summarizes the key components.

The Evaluation Monitoring approach should be used as part of defining the real water quality use impairments that are occurring in the Delta and downstream users of the Delta waters, the cause of the use impairments, and through forensic analysis, the source of the constituents responsible for the use impairments. As organized through my efforts, the Evaluation Monitoring approach is a true watershed based water quality evaluation and management program. In Orange County, the Santa Ana Regional Water Quality Control Board, Orange County Environmental Management Agency, the Transportation Corridor Agency, the Department of Fish and Game, Orange County Water District, and a number of other stakeholders in Upper Newport Bay and Santa Ana river water quality are participants in the Evaluation Monitoring program. I am providing technical leadership for about a $200,000 two-year demonstration project designed to show that alternative approaches for monitoring and management of water quality can, in fact, be readily implemented which define and manage real water quality issues in a technically valid, cost-effective manner.

To the extent that there is interest, I would be happy to devote time and expertise to addressing these issues in Delta water quality where I would provide leadership in working with others to implement an Evaluation Monitoring approach for the Delta where a true watershed water quality management program would be developed and implemented to enhance Delta water quality. I appreciate that many of these issues are already being addressed, however, I also understand that there are some areas that are not being adequately addressed especially as they related to impacts of constituents in Delta waters on aquatic life related beneficial uses of the Delta.

For your information, I wish to bring to your attention that I have established a Web Site (http://members.aol.com/gfredlee/gfl.htm) in which I list Dr. Jones-Lee and my recent papers and reports. We make a number of them available as downloadable files.

Please put me on your committee/subcommittee mailing list to receive announcements of future meetings, correspondence, meeting minutes, etc. Thanks for your assistance. Let me know if I can be of help.

Sincerely yours,

G. Fred Lee, PhD, DEE

copy to: L. Snow

GFL:djc
Enclosure

To: gfredlee@aol.com
From: rwoodard@ncal.net (Richard Woodard)
Subject: CALFED Activities
Cc:
Bcc:
X-Attachments:

Fred: Just a note to acknowledge receipt of your January 14, 1997 correspondence to me. Thank you for the enclosures. Perhaps CALFED may, in the future, be able to implement some of your thoughts on how to perform impairment assessments. Your name was actually added to our mailing list prior to our having received your correspondence. You should see announcements soon for a public workshop on February 4 and a meeting of the Water Quality Technical Group on February 14. Regards. Rick.

Water Quality Evaluation and Management
Solid and Hazardous Waste Landfills

Dr. G. Fred Lee and Dr. Anne Jones-Lee have developed a Web Site:

http://members.aol.com/gfredlee/gfl.htm

in which they list some of their recent professional papers and reports devoted to public health and environmental quality aspects of domestic water supply water quality, water and wastewater treatment, water pollution control, and the evaluation and management of impacts of solid and hazardous waste. The major topic areas of this Web Site are:

- Landfills - Solid and Hazardous Waste Impact Evaluation and Management
- Water Quality Evaluation & Management for Wastewater Discharges and Stormwater Runoff
- Hazardous Chemical Impact - Superfund - Evaluation and Remediation/Management
- Contaminated Sediments - Aquafund - Water Quality Impact Evaluation and Management
- Domestic Water Supply Water Quality - Watershed Management
- Reuse of Reclaimed Wastewaters for Groundwater Recharge and Shrubbery Irrigation
- Excessive Fertilization/Eutrophication of Lakes, Reservoirs, Estuaries, and Marine Waters
- Information on G. Fred Lee & Associates

Some of the papers and reports that they have developed are downloadable from this site. The others are available from:

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Evaluation Monitoring as an Alternative to Conventional Stormwater Runoff Monitoring and BMP Development

G. Fred Lee and Anne Jones-Lee
G. Fred Lee & Associates

There is growing agreement (Urbanos and Torno, 1994; Herricks, 1995; Lee and Jones-Lee, 1994, 1996a;) that conventional stormwater runoff monitoring for a suite of chemicals at the storm sewer outfall or edge-of-the-pavement is of limited value in defining real water quality problems caused by chemicals in stormwater runoff. There is also increasing recognition that conventional best management practices (BMPs) such as detention basins, filters, etc. are not real BMPs for controlling water quality use impairments in waterbodies receiving urban area street and highway stormwater runoff. An alternative monitoring and BMP development approach is "Evaluation Monitoring."

Evaluation Monitoring assesses the impact of stormwater runoff-associated constituents from a water quality use impairment perspective. Conventional monitoring develops chemical data via edge-of-the-pavement sampling and tries, usually with little or no success, to extrapolate to receiving water impacts. Evaluation Monitoring is a watershed-based water quality evaluation and management program in which the stakeholders concerned about water quality in a particular waterbody work together to define the water quality use impairments that are occurring in a waterbody, the cause of the use impairments and develop control programs to limit the amounts of the constituents responsible for the use impairments entering the waterbody of concern.

For example, many heavy metals and organics are of concern in urban area street and highway stormwater runoff because of their potential toxicity to aquatic life. Conventional stormwater runoff monitoring generates data that indicate that potentially significant elevated concentrations of heavy metals are present in urban area street and highway runoff. However, the chemical data developed from such monitoring cannot be used to determine whether the concentrations found in the runoff are in toxic, available forms and whether the toxicity associated with these constituents will be present in the receiving waters at toxic levels for a sufficient time to be significantly toxic to receiving water aquatic life.

Evaluation Monitoring measures the amount of toxicity in the stormwater runoff as it enters the waterbody of concern using US EPA standard ambient water toxicity tests. Where potentially significant toxicity is found in the runoff waters entering a waterbody, site-specific studies are conducted to determine whether the toxicity in a stormwater runoff event is of sufficient magnitude and duration to be potentially adverse to the receiving water aquatic life. If such conditions are found, then through toxicity investigation evaluations (TIEs) the constituents responsible for the toxicity are determined and through forensic studies the sources of these constituents within the watershed are evaluated.

In the Evaluation Monitoring approach, rather than assuming that conventional BMPs, such as detention basins and filters, are effective in controlling potential water quality use impairments in the receiving waters for stormwater runoff, site-specific BMPs are developed to control real water quality use impairments to the maximum extent practicable (MEP). Typically, these BMPs focus on source control that manages the input of the chemical species of concern using BMPs to the MEP. These BMPs, in most cases, will be significantly different from the conventional stormwater runoff BMPs used today since they will focus on dissolved, toxic/available forms rather than particulate, non-toxic forms.

In order to manage water quality problems due to potential bioaccumulatable chemicals such as the chlorinated hydrocarbons and mercury, the focus of Evaluation Monitoring is on determining whether excessive concentrations of these chemicals are found in receiving water fish. Fish tissue analysis is used to determine whether there is a water quality problem due to excessive bioaccumulation. In contrast, conventional stormwater monitoring tries to extrapolate from the constituents in stormwater runoff to tissue concentrations. This approach is normally of limited reliability since there are a variety of factors that influence whether a chemical constituent in runoff waters bioaccumulates to excessive levels in receiving water aquatic organisms. For example, for mercury, the conventional monitoring approach extrapolates from stormwater runoff mercury concentrations to receiving water concentrations of methylmercury which accumulates in fish tissue to excessive levels. Such approaches have limited reliability because of the complexity of the aqueous environmental chemistry of mercury.

Evaluation Monitoring is a cost-effective, technically valid approach for evaluating whether both regulated heavy metals and organics as well as the unregulated constituents in urban area street and highway stormwater runoff are adverse to the designated beneficial uses of the waters receiving the runoff than the currently used conventional monitoring approach. The various potential water quality use impairments of concern such as aquatic life toxicity, domestic water supply, excessive hazardous chemical bioaccumulation, excessive fertilization, sanitary quality, petroleum hydrocarbon - oil and grease, litter and excessive sediment accumulation or impacts are evaluated in the Evaluation Monitoring program in terms of their significance in impairing the beneficial uses of the waterbody (Lee and Jones-Lee, 1996b,c).

Where significant receiving water beneficial use impairment occurs, the waterbody stakeholders work together to define through forensic analysis the sources of constituents responsible for impairment and then develop control programs to control the impairment to the MEP. A three-year demonstration project is currently underway in Orange County, California devoted to the implementation of Evaluation Monitoring for stormwater runoff water quality management for Upper Newport Bay. This program is being conducted in cooperation with the Orange County Environmental Management Agency and the Santa Ana Regional Water Quality Control Board as well as other stakeholders within the Upper Newport Bay watershed.

References

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~~DRAFT~~

Water Column and Sediment Toxics Assessment and Management Issues for the Sacramento River Watershed

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A brief review of some of the issues that should be considered in developing a water quality/sediment quality management program for "toxics" in the Sacramento River watershed is presented below.

Reliability of Chemically-Based Aquatic Toxicity Estimates

- The exceedance of chemical-specific, including site-specific, water quality criteria/standards for potentially toxic chemicals is not reliable for estimating aquatic life toxicity due to the chemical.

- Aquatic life toxicity and excessive bioaccumulation cannot be reliably assessed by measuring the concentrations of chemical constituents in water. At best, chemical concentrations can only be used to indicate that certain regulated chemicals are present in a water at concentrations that under worst-case conditions would be toxic to some forms of aquatic life in some waterbodies.

Chemical approaches for estimating aquatic life toxicity do not address:

- the toxicity or bioaccumulation of unregulated chemicals and combinations of chemicals,

- the aqueous environmental chemistry of potentially toxic chemicals that detoxifies chemical constituents in the Sacramento River system.

In addition to the attached paper, "Evaluation of the Water Quality Significance of the Chemical Constituents in Aquatic Systems: Coupling Sediment Quality Evaluation Results to Significant Water Quality Impacts," Lee and Jones-Lee (1995a, 1996a) "Appropriate Use of Numeric Chemical Concentration-Based Water Quality Criteria" and Lee and Jones-Lee (1993a) "Sediment Quality Criteria: Numeric Chemical- vs. Biological-Effects-Based Approaches" provide additional information on the unreliability of chemically-based approaches for estimating toxicity in waters and sediments.

Assessment of Aquatic Life Toxicity

- Toxicity should be assessed by using several sensitive forms of aquatic life at several times during the year. The spatial and temporal extent of toxicity should be assessed. The US EPA procedures for assessing aquatic life toxicity using fathead minnow larvae and *Ceriodaphnia* (US EPA, 1994) should be used. While the Agency also has a method for estimating the toxicity of constituents in a water to algae, that method does not yield interpretable results that can be used in a toxics management program. Lee and Jones-Lee (1996b) have discussed the inadequacies of that method.

Regulatory Requirements

- The current Central Valley Regional Water Quality Control Board Basin Plan (CVRWQCB, 1994) requires

  "All waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life. This objective applies regardless of whether the toxicity is caused by a single substance or the interactive effect of multiple substances. Compliance with this objective will be determined by analyses of indicator organisms, species diversity, population density, growth anomalies, and biotoxicity tests of appropriate duration or other methods as specified by the Regional Water Board."

- California Department of Health Services (DHS) issues Fish Consumption Advisories for fish and other aquatic life that are judged to have excessive concentrations of ha[illegible]ous chemicals.

- The US EPA and DHS have established drinking water standards (maximum contaminant levels) for potentially hazardous chemicals in domestic water supplies provided to a consumer.

- The US EPA has developed water quality criteria (US EPA, 1987, 1995) and is developing water quality standards for regulated chemicals that are potentially toxic to aquatic life and/or tend to bioaccumulate to excessive levels in higher trophic level organisms used as food. The Water Resources Control Board (WRCB) is developing updated water quality objectives for the state's waters that are designed to protect aquatic life from excessive concentrations of some regulated chemicals that are of concern because of potential aquatic life toxicity or bioaccumulation.

The US EPA water quality criteria and state standards based on these criteria are at this time to be implemented under the Agency's Independent Applicability Policy as stand-alone standards that require compliance in ambient waters beyond the edge of any allowed mixing zone. The US EPA's Independent Applicability Policy is not technically valid (Lee and Jones-Lee, 1995b) and leads to significant over-regulation of chemical constituents in aquatic systems. The US EPA (1996) has announced that it is reviewing the Independent Applicability Policy and could change it so that appropriately developed toxicity information is not subordinate to chemical measurements of potentially toxic chemical concentration-based estimates of aquatic life toxicity information.

Cal EPA Comparative Risk Project

In 1994 the California Environmental Protection Agency Comparative Risk Project released a report (California Comparative Risk Project, 1994) that represented the synthesis of a multi-year, comprehensive, in-depth review of the environmental chemicals and constituents that represent significant human health risks through the atmosphere, drinking water, contact with soils, etc. Several chemicals and pathogenic organisms present in the Sacramento River system were found to represent significant public health threats to the use of these waters for domestic water supply and/or contact recreation. Specific mention of the findings of the Cal EPA Comparative Risk Project results are included in the discussion of the specific toxicants addressed in this report.

Assessing the Water Quality Significance of Aquatic Life Toxicity

- It is inappropriate to assume that a toxic response measured in a laboratory test is of water quality significance in the Sacramento River system.

- The determination of the water quality significance of measured aquatic life toxicity should be evaluated by an expert panel using a non-numeric best professional judgement (BPJ) weight-of-evidence approach. In order to be of water quality-use impairment significance, the toxicity must be of sufficient persistence and extent to significantly adversely impact the numbers, types and characteristics of desirable forms of aquatic life of concern to the public.

- If potentially significant aquatic life toxicity is found in a region, then aquatic organism assemblage studies should be conducted over a least one year, in the fall and spring, to determine if the numbers, types and characteristics of desirable forms of aquatic life are adversely impacted in the region where toxicity is found.

Assessing Excessive Bioaccumulation

- The assessment of excessive bioaccumulation of potentially hazardous chemicals such as mercury, chlorinated hydrocarbon pesticides, PCB's, dioxins and other chemicals must be based on measurement of excessive concentrations in aquatic organism edible tissue that cause a perceived human health hazard when the organism is used as food. Also, as wildlife-based water quality criteria are developed, the presence of excessive concentrations in the whole organism should be assessed relative to these criteria if the organisms that the criteria are designed to protect are present in the watershed and use the organisms of concern as food.

- It should not be assumed that all forms of a potentially bioaccumulatable chemical such as mercury from a particular area in a form or will be converted into a chemical form that is bioaccumulatable. The control of a potential source of a bioaccumulatable chemical should be based on the finding that that source is a source of available forms of the chemical that actually accumulates in aquatic organisms to cause a health hazard.

Base Watershed-Based Water Quality Evaluation and Management Programs on Good Science and Engineering

- The aqueous environmental chemistry and toxicology of chemical constituents of potential concern due to toxicity or bioaccumulation should be appropriately incorporated into a water quality/sediment quality evaluation in order to avoid over-regulation and the waste of public funds in unnecessary treatment/control programs beyond that needed to protect the designated beneficial uses of the Sacramento River and downstream waters. Additional information on incorporation of aquatic chemistry and aquatic toxicology into a watershed-based water quality management program is provided by Lee and Jones-Lee (1996c) "Aquatic Chemistry/Toxicology in Watershed-Based Water Quality Management Programs." Also as they discuss, it is important to consider both nearfield (near the point of discharge-runoff) and farfield (downgradient) impacts of chemical constituents on water quality within a watershed.

Technically Valid Approach for Developing Toxics Control in the Sacramento River Watershed

- The focus of the Sacramento River Toxics Management Program should be on toxicity, not chemical constituents, that under worst-case conditions are toxic to some forms of aquatic life in some waterbodies.

- Since the funds available for the monitoring part of the SRWTCP are limited, it is essential that first priority be given to finding real, significant toxicity and bioaccumulation problems in the Sacramento River watershed. Focusing the SRWTCP monitoring on continued measurement of heavy metals, pesticides and/or other organics provides more data of the type that already exists which show that there are some exceedances of overly protective water quality criteria/standards (objectives). However, no information is provided in this type of monitoring program on whether these exceedances represent real, significant aquatic life toxicity.

  Further, chemical measurements divert funds needed to assess whether real water quality problems-use impairments exist in the Sacramento River watershed. This diversion of funds could jeopardize the success of the SRWTCP in developing the information needed to manage real toxics problems in the watershed.

- The SRWTCP monitoring should first be focused on screening the Sacramento River and its tributaries for aquatic life toxicity and excessive bioaccumulation. Where toxicity and/or excessive bioaccumulation is found, efforts should be devoted to assessing whether the toxicity and/or bioaccumulation is a significant cause of water quality-use impairment.

The SRWTCP should adopt an "evaluation monitoring" approach of the type described by Lee and Jones-Lee (1996d) which focuses on finding real water quality problems due to toxics in the Sacramento River watershed and/or downstream, identifying their cause, determining the source of the constituents that cause the problems and developing control programs that focus on source control.

- Since chemical measurements are unreliable for real water quality problem identification, they should only be used to evaluate the potential cause of measured toxicity as part of a TIE.

- The analytical methods that should be used for toxicity as well as chemical measurements are, in general, the US EPA standard methods. All sampling and measurement methods should use "clean techniques" of the type recommended by the US EPA (US EPA, 1993). For potentially toxic and bioaccumulatable chemicals, the analytical method used must be able to reliably measure the concentration of the chemical of concern at least 0.5 times the US EPA "Gold Book" (1987) or US EPA updated criterion values for metals (1995).

Heavy Metals

- Some parts of the Sacramento River watershed are experiencing water quality problems due to heavy metals. This is of particular importance in areas of acid mine drainage. Potentially toxic heavy metals such as Cu, Zn, Cd, Ni and Cr should be regulated based on toxic forms in the ambient waters and sediments. These forms can not be estimated by chemical measurements. Generally, even properly measured dissolved forms over-estimate the toxic forms of the metal.

Not only must the toxicity of the metal be measured in the discharge and at the point of discharge in the receiving waters, also toxicity measurements must be made downstream of the discharge to be certain that the non-toxic forms do not convert to toxic forms to cause toxicity. Of particular importance is that some regulatory agencies (CVRWQCB) allow the discharge of Cr(III) at 50 μg/L when the US EPA's revised ambient water toxicity-based limit for Cr(VI) is 10 μg/L. Cr(III) is well-known to convert to Cr(VI) under conditions that exist in surface waters. This problem is of particular concern in the waterbodies where the flow in the receiving water for wastewater discharges is primarily the wastewater discharge.

- Mercury and selenium are regulated based on their potential to bioaccumulate in higher trophic level organisms that represent threats to higher trophic level organisms that use lower trophic levels as food.

- Mercury is the cause of significant water quality problems within and downstream of the Sacramento River system. Mercury present in the Sacramento River system is derived from mercury mining wastes, the use of mercury in previous gold recovery operations and domestic wastewaters as well as other sources. Most of the sources of mercury in domestic wastewaters are unknown at this time. It is important that the source(s) of the mercury that bioaccumulates in organisms in various parts of the watershed and downstream become better understood.

Mercury should be regulated based on measurements of methylmercury since this is the bioaccumulatable form. The regulation of mercury inputs to a waterbody should be based on regulating those forms of mercury that convert to methylmercury in a waterbody that is experiencing or could experience bioaccumulation to a sufficient extent to be hazardous to the public who consume fish from the waterbody.

- Selenium is of concern because of bioaccumulation that is adverse to waterfowl reproduction. While this problem has been found in San Joaquin Valley wetlands, it is also of potential concern in the San Francisco Bay area due to wastewater discharges of selenium. There is need to evaluate whether selenium is a cause of water quality problems in the Sacramento River system.

- At this time arsenic is not considered a significant cause of water quality problems in the Sacramento River system. However, there is growing understanding that arsenic is a potentially significant carcinogen in domestic water supplies. The Cal EPA Comparative Risk Project ranked arsenic as a potentially highly significant carcinogen in the state's waters (California Comparative Risk Project, 1994). The US EPA has proposed to reduce the acceptable arsenic concentrations in domestic water supplies to 20, 2, or 0.2 μg/L. Adopting one of the lower proposed regulatory levels would cause some of the surface and groundwaters in the Sacramento River system to be considered hazardous for use as a domestic water supply without treatment for arsenic removal. The arsenic is derived from natural sources as well as the activities of man. There is need to monitor arsenic concentrations in surface and groundwaters to about 1 μg/L in anticipation of pending regulatory requirements.

Pesticides and Related Compounds

Pesticides, herbicides, fungicides and related chemicals (pesticides *et al.*) are highly toxic to some forms of life. While they are designed to be toxic to the specific target organism(s), often their toxicity extends well beyond the target organisms that represent threats to agriculture, commercial and industrial activities and residential areas. The Cal EPA Comparative Risk Project (1994) ranked pesticides as a highly significant threat to public health within the state. Further, as discussed below, some pesticides are significant threats to aquatic life.

- Organophosphorus pesticides used by agriculture and in urban areas cause significant acute aquatic life toxicity in the Sacramento River watershed. The level and persistence of this toxicity is such that it is in violation of the CVRWQCB (1994) Basin Plan requirements for the control of aquatic life toxicity. There are, however, significant problems in regulating this toxicity due to the fact that the regulatory agencies have not developed water quality criteria/ standards for several of the key compounds, such as diazinon, that cause this toxicity. Further, agricultural discharge of pesticides and other chemicals, even though highly toxic or adverse to water quality, is not subject to NPDES permit limitations.

There is need to better understand the water quality significance of the high levels of organophosphorus pesticide-caused acute aquatic life toxicity that occurs in the Sacramento River

- In addition, algae and other aquatic plants cause deteriorated water quality through aesthetic impairment of recreation uses. This type of problem is becoming highly important in the Delta due to aquatic weed growth.

- The algae and other plants that develop due to the discharged N & P compounds to the Sacramento River and tributaries also contribute to domestic water supply water quality deterioration through causing taste and odors, shortened filter runs and, most importantly, contributing to the trihalomethane (THM) precursors. THM's are the result of chlorination of water supplies where the chlorine reacts with dissolved organic carbon (DOC) (THM precursors) derived from terrestrial and aquatic plants that are present in irrigation drainage and runoff waters, urban area stormwater runoff and domestic and industrial wastewater discharges.

THM's are of public health concern because they are regulated as human carcinogens. An MCL of 100 $\mu g/L$ was established for the total THM's which attempted to balance the early 1980 perceived cancer risk associated with consumption of THM's (chloroform and other related chemicals) and the health risks associated with inadequate disinfection of water supplies. This approach leads to a relatively high cancer risk (about one cancer in 10,000 people) for waters that meet the THM limit compared to the normal cancer risk that is considered acceptable in domestic water supplies today of one additional cancer in one million people who consume the THM-containing water over their lifetime. The Cal EPA Comparative Risk Project (1994) ranked THM's as one of the potentially significant causes of cancer in California.

The US EPA will soon revise downward the THM drinking water standard and will release several new MCL's for newly recognized THM's. The Agency will also soon require that dissolved organic carbon (DOC) in a domestic water supply be controlled to reduce the THM content of treated drinking water. This is prompting the examination of DOC sources within the Sacramento River system as precursors to carcinogens that are produced in domestic water supplies that use the Sacramento River system waters as a source of domestic water supply. There are about 20 million people in the state of California who use these waters for domestic water supply purposes.

Lee and Jones (1991a,b) have discussed the algal nutrient-domestic water supply water quality issues in the Delta. They report that significant water quality problems are occurring that are due to the discharge of THM precursors and aquatic plant nutrients to the Sacramento-San Joaquin River systems. There is need to better understand the sources of DOC and aquatic plant nutrients that lead to increased THM's in domestic water supplies in the Sacramento River system and downstream.

While not practiced in the Sacramento River system, there are about 50 million people in the US and other countries who treat their domestic wastewaters for control of nitrogen and/or phosphorus compounds for the purpose of reducing algal growth in the receiving waters for the wastewater discharges. Further, there are some areas, such as the Chesapeake Bay region of the East Coast and the Great Lakes region, where agricultural activities are being significantly modified to control nutrient runoff from agricultural lands. Since aquatic plant nutrients contributed to the Sacramento River system are a highly significant cause of water quality problems (toxicity to humans and aquatic life) within the system and downstream, there is need to critically examine whether wastewater dischargers and agricultural activities should be required to control nitrogen and phosphorus compounds in their discharges-runoff waters in order to reduce the toxicity caused by these chemicals.

Therefore, the fertilizers used on land that result in runoff that contains increased DOC as well as nutrients (N & P) present in rural, agricultural and urban stormwater runoff, drainage and wastewater discharges in the Sacramento River watershed lead to "toxicity" to humans through production of potential carcinogens (THM's). In addition, as discussed by Lee and Jones-Lee (1996e) the growth and death of algae and other plants lead to low dissolved oxygen and the associated H_2S and NH_3 in the Sacramento River system and downstream sediments. The N & P derived toxicity causes sediment toxicity in many parts of the Sacramento River watershed and downstream, such as in the Delta and San Francisco Bay. The water quality significance of this toxicity is not understood at this time.

Pathogenic Organisms

- The SRWTCP stakeholders have defined "toxicants" as any constituent that is adverse to public health and the environment. This definition includes pathogens that impact the sanitary quality of water for use in domestic water supplies and for contact recreation. The Cal EPA Comparative Risk Project (1994) concluded that waterborne pathogens were a significant threat to public health within the state through domestic water supplies and possibly through contact recreation.

During the summer of 1995 the Santa Monica Bay Restoration Project (1996) conducted a study of the public health hazards associated with contact recreation in the beachwaters of Santa Monica Bay near storm sewer discharges. The concern was the presence of human pathogens that are present in the dry weather flow that occurs in these storm sewers. They found a significant correlation between various types of diseases and contact recreation in close proximity to the storm sewer discharges. These findings are part of the growing recognition that people are becoming ill due to contact recreation in surface waters.

Lee and Jones-Lee (1993b, 1994a, 1995c,d) have reviewed the public health significance of bacteria, enteroviruses and cyst-forming protozoans as a cause of human disease through water supplies and contact recreation. The 1993 Milwaukee *Cryptosporidium* incident in which 400,000 people became ill and about 100 people died due to *Cryptosporidium* that passed through conventional domestic water supply treatment has prompted widespread review and investigation of waterborne pathogens in surface waters that are a threat to domestic water supplies and those who contact recreate in these waters.

In addition to domestic wastewaters being a source of these pathogenic organisms, certain agricultural and animal husbandry activities, such as dairies and feedlots, contribute *Cryptosporidium* to surface waters.

At this time, the sources, occurrence and water quality significance of waterborne pathogens in the Sacramento River watershed are poorly understood. This is an area that needs attention as part of the SRWTCP. There is need to expand the sanitary quality monitoring program to include more comprehensive coverage of domestic water supply watersheds, contact recreation areas and public health risk of contact recreation in the Sacramento River system. The sanitary quality monitoring program should include total and fecal coliforms, *E. coli*, fecal streptococcus, enteroviruses-bacteriophages, *Cryptosporidium* and *Giardia* at quarterly intervals during the fall, winter and spring and monthly during the contact recreation period, principally late spring, summer and early fall.

Groundwater Quality Protection

While surface water toxicity is the focus of the SRWTCP, because of the importance and intercoupling of surface and groundwaters in the watershed, it is important to protect the quality of groundwater resources in the Sacramento River system.

- At this time, groundwaters are not being protected from pollution by hazardous and deleterious chemicals present in solid wastes that are managed by landfilling. While current regulatory requirements prohibit groundwater pollution by landfills, inactive and active municipal and industrial landfills and other waste disposal areas are polluting groundwaters with leachate that contains highly hazardous and deleterious chemicals that render the groundwater near these waste disposal areas unusable for domestic water supply purposes. Further, landfills are being permitted today that will, at best, only delay when groundwater pollution occurs. There is inadequate enforcement of current WRCB Chapter 15 regulatory requirements which require that landfills be designed, constructed, operated, closed and maintained during the post-closure period so that no pollution of groundwaters occurs for as long as the wastes in the landfill are threat. There is need to improve the implementation of current regulatory requirements.

Widespread pollution of groundwaters has occurred and is occurring by nitrogen fertilizers (nitrate) typically applied as ammonia, possibly by pesticides and other hazardous chemicals associated with agricultural activities. The current regulatory requirements are highly ineffective in preventing the pollution of groundwaters by agricultural activities. There is need to require that all users of nitrogen fertilizers and other agricultural chemicals monitor the groundwaters that could be impacted by fertilizer-chemical applications to detect potential groundwater pollution before widespread pollution occurs.

While there is limited opportunity to develop additional surface water supplies within the state to meet ever-increasing water supply needs for communities, agriculture, recreation and fish and aquatic life, the future development of water supplies in the state will be directly dependent on enhancing the use of the state's groundwaters and groundwater aquifer system. It is essential to future generations' water supply that the widespread, current groundwater pollution that is being allowed to occur through inadequate implementation of current regulations and through inadequate regulations be controlled. Lee and Jones-Lee (1994b) have reviewed the issues of groundwater pollution within the state and have recommended procedures that could, if implemented, begin to effectively address them.

Because of the highly significant threat that the agricultural use of fertilizers and other chemicals represent to public health through pollution of groundwaters and the importance of the groundwaters in the Sacramento River system to the region and the state, regulatory programs should be developed and, most importantly, be implemented and enforced to stop further groundwater pollution from all sources. Particular attention should be given to controlling agricultural activities, and municipal and industrial solid and liquid waste disposal practices that lead to groundwater pollution. Failure to develop and implement these programs will result in continued groundwater pollution in the Sacramento River system. This will be significant to the surface water resources of the system since there will be less groundwaters available for use within the watershed and in other parts of the state.

Additional Information

Additional information on these issues as applied to the Sacramento River system is available upon request.

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Assessing Water Quality Impacts of Stormwater Runoff

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Abstract

Current "water quality" monitoring of non-point source runoff typically involves periodically measuring a laundry list of chemicals in the runoff waters. This approach, while satisfying regulatory requirements, provides little to no useful information on the impact of the chemicals in the runoff on the real water quality - designated beneficial uses of the receiving waters for the runoff. There is need to focus water quality monitoring on investigating the receiving waters in order to assess whether the chemicals in the runoff are adversely affecting beneficial uses. This paper presents an evaluation monitoring approach for monitoring receiving waters that determines whether the runoff is a significant cause of water quality - use impairments. For each type of use impairment, such as aquatic life toxicity, excessive bioaccumulation of hazardous chemicals, excessive fertilization, etc., highly focused site-specific studies are conducted to determine the use impairment that is likely occurring due to a stormwater runoff event(s) and the specific cause of this impairment.

Introduction

There is growing recognition that domestic and industrial wastewater and stormwater runoff "water quality" monitoring involving the measurement of a suite of chemical "pollutant" parameters in discharge/runoff waters is largely a waste of money. For stormwater runoff, such programs generate more data of the type that have been available since the 1960's on the chemical characteristics of urban area, highway and street runoff. It has been known since that time that runoff from these areas contains a variety of regulated chemical constituents and

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waterborne pathogenic organism indicators that exceed water quality standards at the point of runoff discharge to the receiving waters. However, discharge monitoring provides little to no useful information on the impacts of the apparently excessive regulated chemicals and unregulated chemicals in the discharge on receiving water water quality - designated use impairment. As discussed by Lee and Jones (1991) and Lee and Jones-Lee (1994a, 1995a,b), many of the chemical constituents in urban stormwater runoff are in particulate, non-toxic, non-available forms. Further, the short-term episodic nature of stormwater runoff events means that significant exceedance of US EPA water quality criteria and state standards based on these criteria can occur in the receiving waters for the runoff without adversely impacting receiving water beneficial uses. These issues have recently been reviewed by Lee and Jones-Lee (1995c,d).

The failure of the US EPA and the states to properly assess real water quality use impairment associated with stormwater runoff from urban areas and highways has resulted in highly unreliable reporting of water quality problems in the nation's waters due to urban stormwater runoff (Lee and Jones-Lee, 1994b). Further discussion of the significant over-regulation that is occurring today in implementing water quality standards into permit discharge loads is provided by Lee and Jones-Lee (1995a,e).

In 1994, the Engineering Foundation held a Stormwater Quality Monitoring Conference to discuss current problems with conducting technically valid, cost-effective monitoring of urban stormwater runoff water quality. There was general consensus at that conference that a significantly different approach needs to be taken in monitoring stormwater runoff events from urban areas, highways, streets and industrial areas (Torno, 1994). While not addressed at that conference, the same situation applies to runoff from agricultural and rural lands. Additional information on why there is need for a different approach for assessing the water quality impacts of stormwater runoff as well as developing management approaches for chemical constituents in this runoff is provided in the Stormwater Runoff and Receiving Systems: Impact, Monitoring, and Assessment conference proceedings (Herricks, 1995).

The basic problem is that so little is known about the real adverse impacts of urban area and highway/street runoff that it is not possible to develop an appropriate runoff water quality monitoring program based on the measurement of water quality characteristics at the point of discharge of the runoff into the receiving waters. In order to develop a program of this type, it is essential that a well-defined, site-specific understanding of the relationship between concentrations of constituents measured in the runoff waters and the site-specific water quality impacts that these constituents have on the designated beneficial uses of the receiving waters for the runoff be developed.

Technically valid, cost-effective stormwater runoff monitoring programs should focus on monitoring those constituents in the runoff that cause significant water quality use impairments in the receiving waters for the runoff. The first step to developing a technically valid stormwater runoff water quality monitoring program is the evaluation of the water quality impacts caused by the constituents in the runoff that adversely impact receiving water quality. Monitoring programs that fail to focus on water quality problem issues fail to provide the information needed to effectively manage stormwater runoff quality.

In an effort to address the problems with current stormwater runoff water quality monitoring programs, the authors have developed what they term "evaluation monitoring." Evaluation monitoring focuses on highly selective, site-specific evaluation of the potential for chemical constituents and pathogenic organisms in the runoff waters to cause site-specific use impairments of the receiving waters for the runoff.

Principles of Evaluation Monitoring

The basic approach used in evaluation monitoring of stormwater runoff impacts is the determination of whether the chemical and other constituents in the runoff waters, either alone or in combination with other constituents in the receiving waters for the runoff, cause a significant adverse impact on the designated beneficial uses of these waters to require constituent control, including possibly treatment of chemical constituents in the runoff waters, to eliminate the impact. The initial focus of evaluation monitoring is not the traditional approach of measuring the concentrations of specific constituents in the runoff waters but is water quality - use impairment. For example, a number of the chemical constituents in highway/street and urban area runoff waters are of concern because of their potential toxicity to aquatic life in the receiving waters which could significantly alter the numbers, types and characteristics of desirable forms of aquatic life in these waters. In evaluation monitoring, rather than trying to estimate toxicity from chemical constituent concentrations, toxicity of the receiving waters is measured directly. Toxic effects of concern include acute and chronic toxicity which is manifested in death, impaired growth and impaired reproduction.

In addition to the classical toxic effects associated with chemical constituent impacts on aquatic life, there is also concern about chemicals and pathogenic organisms that cause adverse impacts on aquatic life through the growth of tumors, organ disfunction - lesions, etc. While the classical toxic effects of heavy metals, etc. are usually manifested in a few days to a few weeks during sensitive life stages of the organism, the carcinogenic, teratogenic and mutagenic impacts on aquatic organisms typically take longer periods of time to develop.

D-044163

Another potential water quality problem associated with highway/street and urban area runoff is the potential for chemical constituents in this runoff to accumulate within edible organism tissue to sufficient concentrations to be a health hazard to those who consume the organisms as food, i.e. cause the organisms to receive a human health advisory. Also of concern is the accumulation of chemical constituents in aquatic life to a sufficient extent to be adverse to higher trophic level organisms such as fish-eating birds and other wildlife.

Other water quality problems of concern associated with stormwater runoff include excessive fertilization of the receiving waters for the runoff which impairs the use of the waterbody for recreation and domestic water supply purposes. Also of concern is the presence of waterborne pathogenic organisms that can impact the sanitary quality of the receiving waters through impaired contact recreation (beach closings) and shellfish harvesting. Further, litter in highway/street and urban area runoff can impair recreational use of receiving waters. Page limitations on this paper preclude the presentation of detailed discussions of approaches for implementing evaluation monitoring.

The authors have developed an application of this approach for the development of the Eastern Transportation Corridor (ETC) which is a new toll road that is currently under construction located in Orange County, California. This approach is being used to develop technically valid, cost-effective stormwater runoff BMP's for this highway.

Evaluation Monitoring vs. Mechanical Monitoring of Receiving Waters

The traditional approach frequently used in ambient water water quality studies is to develop a sampling program where certain physical, chemical and biological parameters are mechanically sampled and analyzed for an arbitrarily developed period of time, usually one year. At the end of this time, attempts are made to try to discern from the data collected water quality impacts of certain discharges - runoff to the waterbody. Often studies of this type yield inconclusive results as a result of there being an insufficient number of samples taken and insufficient number of analyses made of the key parameters at appropriate times to reflect true water quality impacts of the runoff.

Lee and Jones (1983) have discussed the importance of not following the traditional approach of passively examining the data collected in the water quality monitoring program after collection for information on water quality impacts. This "passive" approach toward data review, while easily administered and carried out, frequently fails to provide key information on impacts during critical periods of the year at times when the primary water quality impacts occur. They recommend that "active" water quality monitoring programs be conducted where data analysis proceeds at the time of data collection in which the results of the recent sampling and analyses are used to determine the adjustments in the study program that need to be made as the study program is being carried out to utilize the funds available for the study in the most cost-effective, technically valid manner. The adoption of the evaluation monitoring approach described herein focuses the resources available on defining major real water quality impacts during the time and under the conditions where and when the impacts are most likely to occur.

Conclusions

It is now widely recognized that the monitoring of stormwater runoff from highway/street, urban areas, industrial properties and rural areas involving measurement of a concentration of a few chemical parameters in a few runoff events each year is largely a waste of money. There is general agreement that there is need to shift the monitoring to evaluation of impacts of stormwater runoff in the receiving waters for the runoff. The focus of the monitoring program should be devoted to biological effects-based parameters, such as aquatic life toxicity and bioaccumulation, and water quality - use impairment, such as closure of beaches and shellfish harvesting due to excessive coliform concentrations, etc. The monitoring of specific chemical constituents in the receiving water's water column and sediments should only be undertaken if the effects-based parameters, such as toxicity, show that the receiving waters for the stormwater runoff are experiencing significant impairment of the designated beneficial uses for these waters.

When such impairments are found, then site-specific studies directed toward determining the cause of the impairment including the specific chemical forms or organisms responsible for it, as well as the specific sources of those chemical forms or organisms that cause the use impairment in the stormwater runoff should be conducted. Best management practices should be developed to the maximum extent practicable to control real pollutants associated with stormwater runoff. An evaluation monitoring program of the type described in this paper provides the technical base of information necessary to develop technically valid, cost-effective control of real water quality problems associated with urban and rural stormwater runoff.

Additional Information

Cited in the text and listed in the references are a number of reports developed by the authors which provide background information important to developing valid evaluation monitoring programs. Copies of the authors' papers and reports on this topic, including the specific application of evaluation monitoring to the Eastern Transportation Corridor highway in Orange County, California, are available from them upon request.

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D-044167

Assessing Water Quality Impacts of Stormwater Runoff

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Conventional Water Quality Monitoring - Management Approach "Compliance Monitoring"

- Monitor Concentrations of Selected Regulated Chemicals in Runoff Water
- Compare Monitoring Results to Accepted Discharge Limits and Ambient Water Quality Standards
- If "Excessive" Concentrations (Loads) Found in Discharge, Reduce Discharge of Chemical Constituents to Achieve Regulatory Compliance with Water Quality Standards

Focus of Conventional Approach Is Control of Chemicals in Discharge to Achieve Allowed Concentrations (Loads)

Conventional Chemical Approach Not Technically Valid for Stormwater Runoff - Leads to Over-Regulation and Waste of Funds and/or Under-Regulation of Unregulated Constituents

Orange County Area Highway Stormwater Runoff Chemical Characteristics Caltrans District 8 & 12 (1994)

Parameter	Detection Units	Chapman Ave (I-5, PM34.7)	Walnut Ave (SR-55, PM14.2)
Total Suspended Solids	mg/l	85	100
Total Dissolved Solids	mg/l	12	12
Chemical Oxygen Demand	mg/l	42	24
Oil and Grease	mg/l	5.3	2.5
Fecal Coliform	ml	<2/100	50/100
pH	unit	7.0	9.1
Total Residual Chlorine	mg/l	0.45	<0.20
Nitrate	mg/l	0.43	0.37
Nitrite	mg/l	0.051	0.042
Ammonia	mg/l	1.3	0.9
Total Kjeldahl Nitrogen	mg/l	0.89	1.4
Total Phosphorus	μg/l	120	130
Dissolved Phosphorus	μg/l	130	120
Sodium	μg/l	3000	1500
Cadmium	μg/l	<5	8
Copper	μg/l	24	22
Lead	μg/l	48	160
Chromium	μg/l	<10	<10
Zinc	μg/l	180	140
Iron	μg/l	3400	3400
Nickel	μg/l	<32	<32
Magnesium	μg/l	1300	1300

Management of Urban and Highway Stormwater Runoff

Stormwater Runoff NPDES Permit Holders Required to Control *Pollution - Use-Impairment* in Receiving Waters for Runoff to the *Maximum Extent Practicable* (MEP) through the Use of *Best Management Practices* (BMPs)

NPDES Stormwater-Permitted Discharges Must Meet Water Quality Standards in Receiving Waters for the Runoff

However, Failure to Meet Standards Not Permit Violation

Current Water Quality Criteria/Standards Not Appropriate for Regulating Stormwater Runoff Water Quality

Waste Public and Private Funds

Lead to Over-Regulation of Runoff

Facts to Consider:

- Non-Toxic, Unavailable Forms
- Limited Exposure of Aquatic Organisms in Receiving Waters Due to Short-Term, Episodic Nature of Stormwater Discharges

Non-Protective - Under-Regulation

- Does Not Address Unregulated Chemicals, e.g., Diazinon

D-044167

Stormwater Runoff Management Issues

- Monitoring of Urban Area and Highway Stormwater Runoff Shows Concentrations of Some Chemical Constituents above Water Quality Criteria/Standards

  Does This "Exceedance" Lead to Pollution - Impairment of Designated Beneficial Uses?

  Water Quality Criteria/Standards Are Overly-Protective

    Do Not Properly Consider Aquatic Chemistry - Toxicology (Duration of Exposure)

    Few Documented Cases of Real Water Quality Use-Impairment Due to Urban Area and Highway Stormwater Runoff

  US EPA & Congress, as Part of Reauthorization of Clean Water Act, Recognize Over-Protective Nature of Water Quality Criteria/Standards When Applied to Stormwater Runoff

    Develop Wet-Weather Standards/Implementation Approach

    Exempt from Use-Attainment during Runoff Event

- Conventional Stormwater BMPs Such as Detention Basins, Sand and Other Filters, Grassy Swales Not Reliable for Control of Real Water Quality Problems Due to Toxics, Nutrients, Pathogens, etc.

  Only Potentially Applicable to Control of Erosion - Silt

    Not a Problem in Most Established Areas

- High Cost to "Treat" Stormwater Runoff to Achieve Water Quality Standards

  Cities, Highway Departments Have Limited Funds to Devote to Stormwater Runoff Quality Management

- Must Use Funds Available to Control *Real, Significant* Water Quality Use-Impairments of Importance to Public

- Current Stormwater Runoff Water Quality Monitoring Programs for Urban Areas and Highways Involving Monitoring Runoff for Suite of Chemical Constituents Provides Little New Useful Information

  Results Already Known from Past Monitoring of Similar Areas

  Provides No Information on Impact of "Excessive" Regulated Chemicals and Unregulated Chemicals in Runoff on the Receiving-Water Quality - Impairment of Designated Beneficial Uses

  Unregulated Chemicals May Be Most Important Causes of Receiving-Water Impacts

    e.g., Diazinon - Organophosphorus Pesticide Causes Stormwater Runoff to Be Toxic in Many Areas

    Issue: Is the Toxicity of Sufficient Magnitude and Duration to Impair Beneficial Uses of Receiving Waters?

  Regulate about 200 of the 60,000 Chemicals in Use Today

Develop Alternative Approach for Assessing Stormwater Runoff Impacts and BMP Development

Mechanical/Routine Monitoring of Receiving Waters for Stormwater Runoff

- Very Expensive
- Will Not Likely Detect Stormwater Runoff Impacts

Focus Stormwater Runoff Monitoring on Runoff Events

Should Shift Monitoring to Receiving Waters for Runoff

Evaluation Monitoring

  Focus Monitoring Funds on Finding Real Water-Quality/Use-Impairments - Pollution - in Waters Receiving the Runoff, That Are Caused by the Runoff

Types of Potential Water Quality Impacts Use-Impairment - Pollution

- Drinking Water Use-Impairment - Surface and Groundwater
- Aquatic Life Toxicity in Water Column and/or Sediments
- Excessive Bioaccumulation - Human Health &/or Wildlife
- Suspended Sediment - Turbidity - Siltation - Habitat Impacts
- Excessive Fertilization/Eutrophication - Nutrients - N & P
- Pathogenic Organism Indicators
- Low Dissolved Oxygen
- Aesthetics -- Litter, Debris, Oil Sheen, etc.

Types of Potential Water Quality Impacts Use-Impairment - Pollution (continued)

Questions That Should Be Addressed

- Is There Significant Toxicity in the Receiving Waters That Is Associated with Runoff Events?
- Are There Closed Shellfish Beds, Swimming Areas, etc.?
- Is There Excessive Algal/Aquatic Weed Growth?
- Is There Litter and Debris?
- Do the Fish and/or Shellfish Contain Excessive Concentrations of Hazardous Chemicals?
- Is the Water Turbid? Is There Shoaling, Burial of Spawning Areas, Shellfish Beds, etc.?
- Are Domestic Supplies Experiencing Treatment Problems, Excessive Costs?

Define the Most Important Water Quality Use-Impairments in the Receiving Waters That Are Potentially Due to Stormwater Runoff

D—044168

Evaluation Monitoring

Stormwater Dischargers Work with Regulatory Agencies, Point-Source Dischargers, Potentially Impacted Public Such as Water Utilities, etc. and Others as Appropriate to Determine If the Receiving Waters for the Stormwater Runoff Experience Real, Significant Water Quality Use-Impairments Due to Stormwater Runoff - Use Watershed Approach

Develop Evaluation Monitoring Program That Focuses the Financial and Other Resources Available on Funding Real Water Quality Problem Identification and Management Associated with Stormwater Runoff

Rather Than Focus on Chemicals, Focus on Chemical Impacts

Potentially Toxic Chemicals vs. Toxicity

Use Toxicity Tests to Integrate All Potentially Toxic Chemicals (for Both Regulated and Non-Regulated Chemicals) in the Receiving Waters

Development of New Stormwater Runoff BMPs

If Water Quality Use-Impairment Found in Receiving Waters for Stormwater Runoff Determine If This Use-Impairment Likely Due, to Significant Extent, to Urban Area or Highway Runoff

If Real, Significant Water Quality Use-Impairments Found That Are Associated with Stormwater Runoff

- Determine Cause - Chemical Toxicity Identification Evaluation (TIE)
- Determine Source - What Is the Origin of the Specific Chemical Constituent That Causes the Use-Impairment for the Urban Area - Highway Runoff?

Develop BMPs to Control Cause of Use-Impairment to the Maximum Extent Practicable - Focus on Source Control BMPs

If Stormwater Runoff Causes Real, Significant Water Quality Use-Impairment, Determine If Chemical or Pathogens Can Be Controlled at the Source to Urban Area - Highway That Leads to Stormwater Runoff That Causes Pollution in the Receiving Waters

(continues)

Development of New Stormwater Runoff BMPs (continued)

If Chemical, Pathogens, Litter, etc. Cannot Be Controlled at Source, Develop *Site-Specific* Treatment Approaches If Economically Feasible

Repeat Evaluation Monitoring Program Every 5 Years to Detect:

- New Water Quality Use-Impairments Due to Increased Loads and/or New Pollutants in the Stormwater Runoff
- New Information on Assessing Water Quality Impacts for a Chemical
- Evaluate Effectiveness of BMPs in Improving Receiving Water Water Quality

Overall

Find a Real Water-Quality/Use-Impairment

Determine Its Cause and Source

Develop Site-Specific BMPs to Achieve Control to MEP

Technically Valid, Cost-Effective, Common Sense Approach That Leads to Wise Use of Public Funds

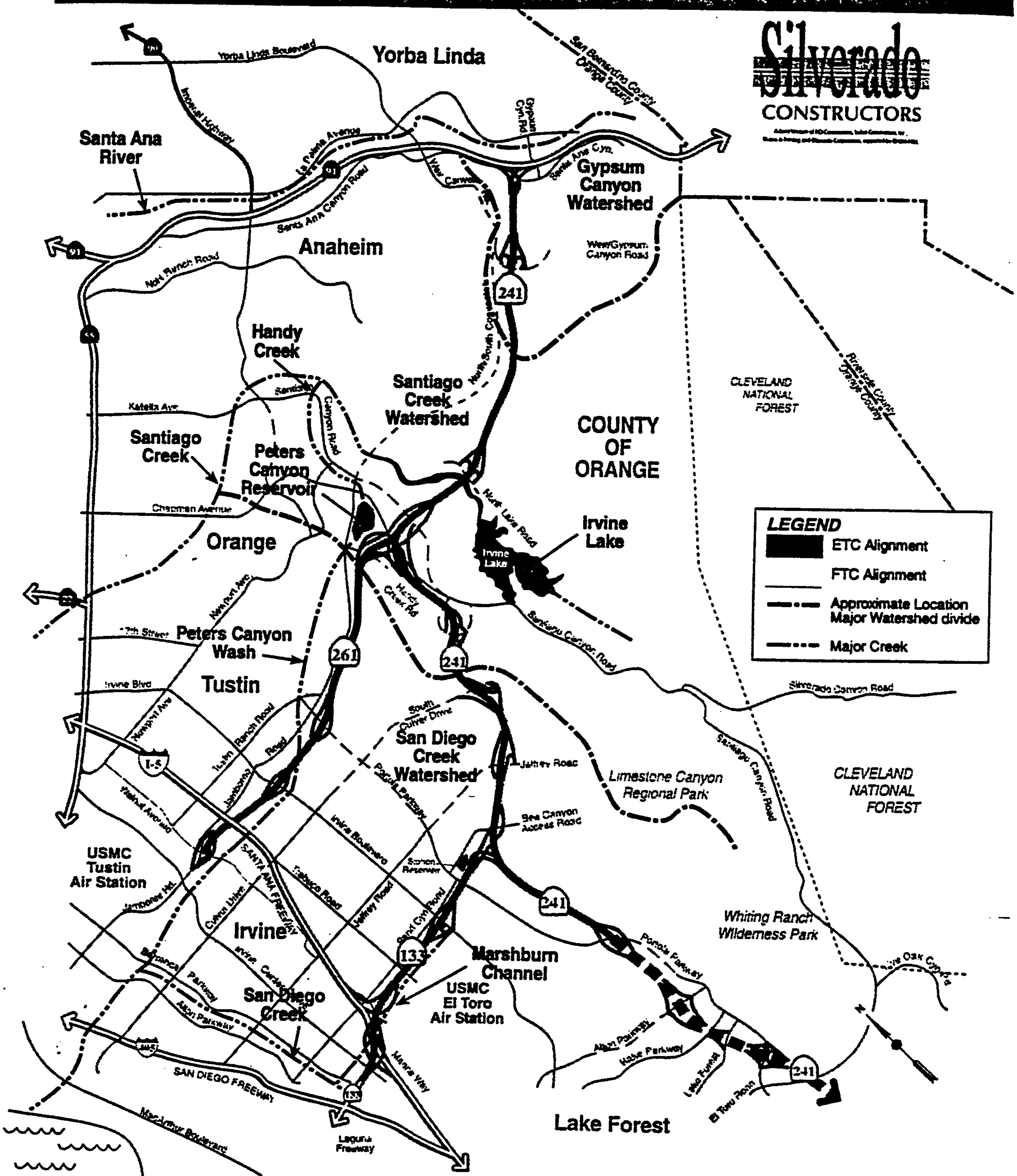
Water Quality Use-Impairment
◂ *Problem Identification* ▸

Consider the Following Types of Possible Impairments:

- Impairment of Domestic Water Supply Water Quality
- Aquatic Life Toxicity
- Excessive Bioaccumulation of Hazardous Chemicals
- Sediment Toxicity That Impairs Water Quality
- Eutrophication - Excessive Fertilization
- Sanitary Quality Impairment of Contact Recreation and Shellfish Harvesting
- Oil and Grease Accumulation
- Significant Dissolved Oxygen Depletion
- Litter Accumulation
- Siltation - Excessive Sediment Accumulation

(continues)

EASTERN TRANSPORTATION CORRIDOR
State Route 241 & 261



Map base by CDMG

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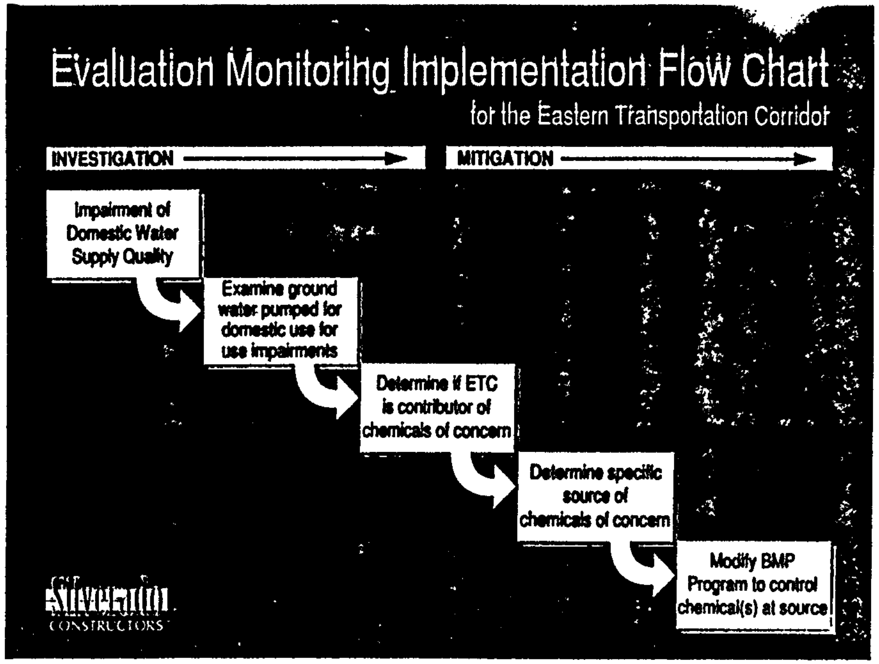
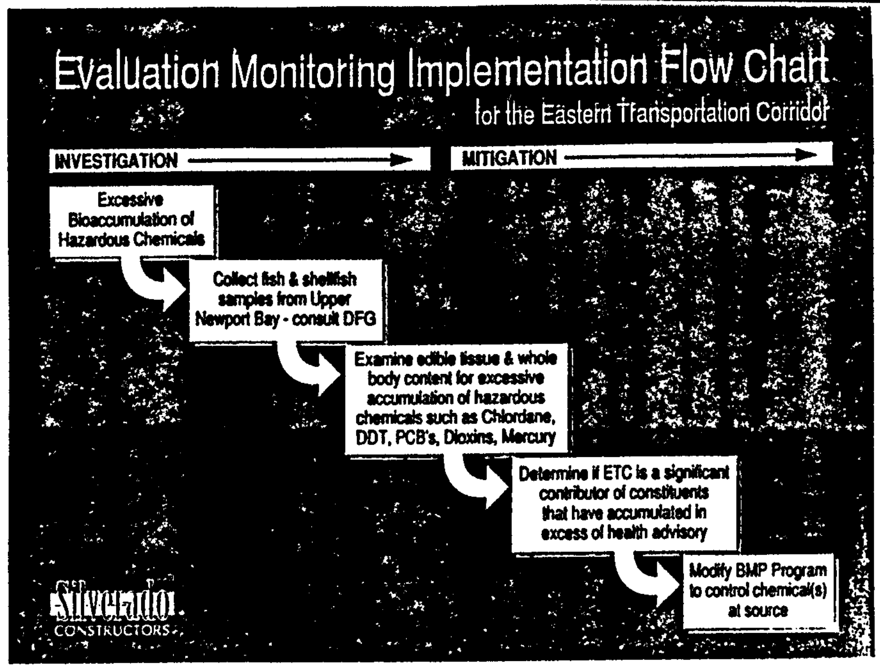
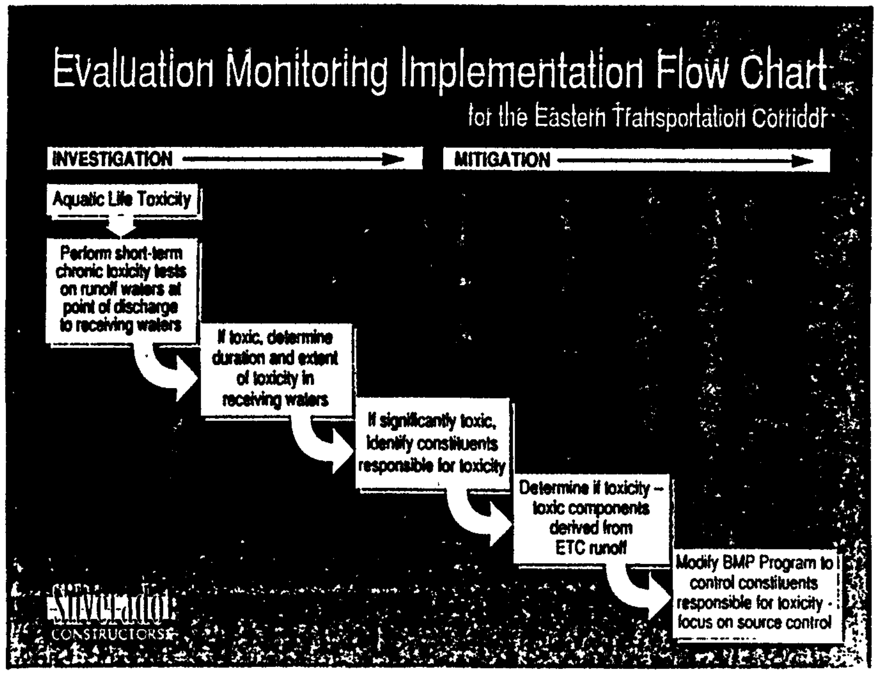
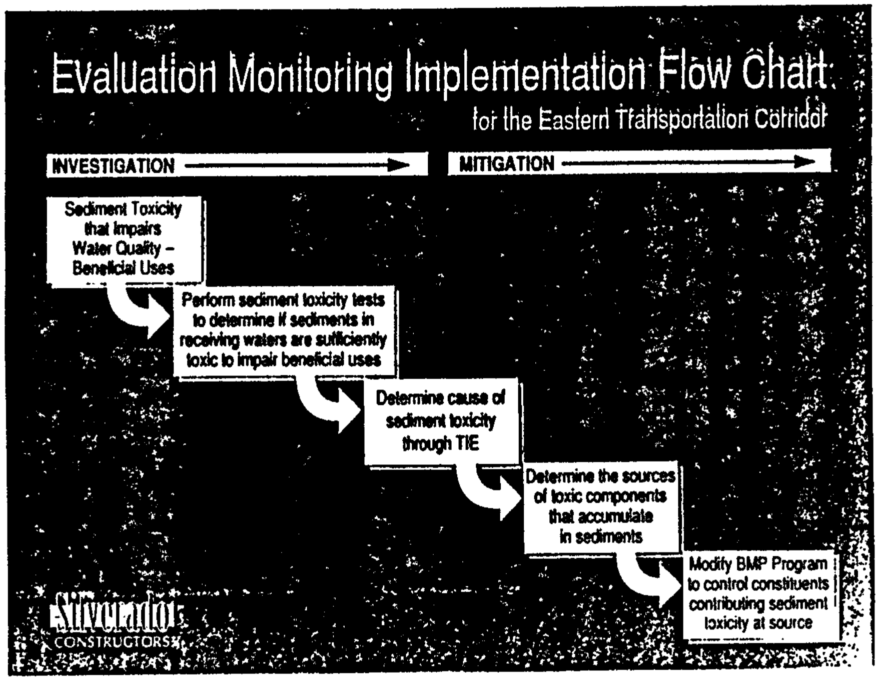
Plate 3-2
Principle Receiving Wate
Runoff Management Plan









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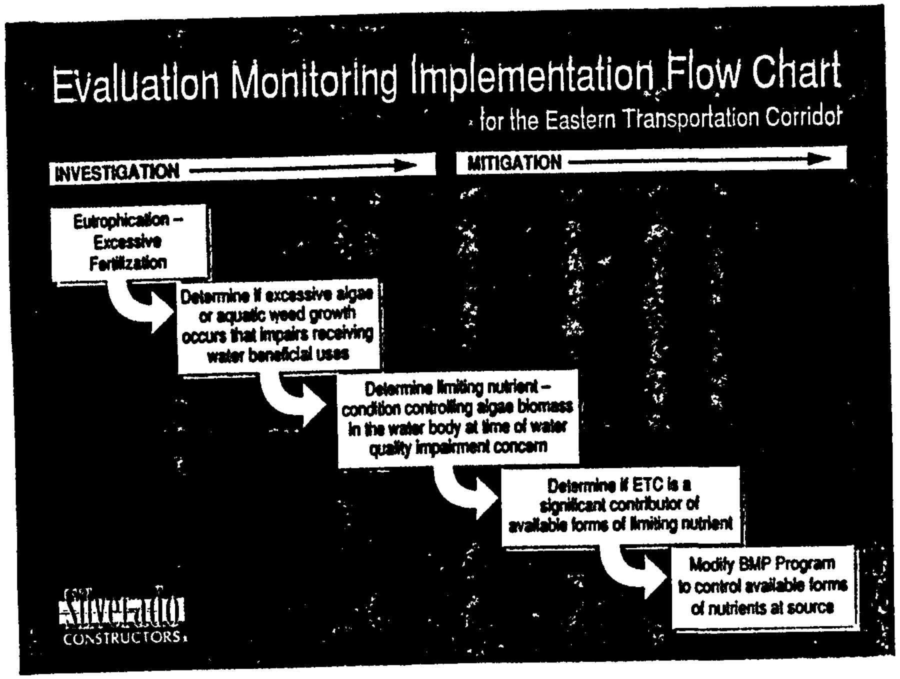
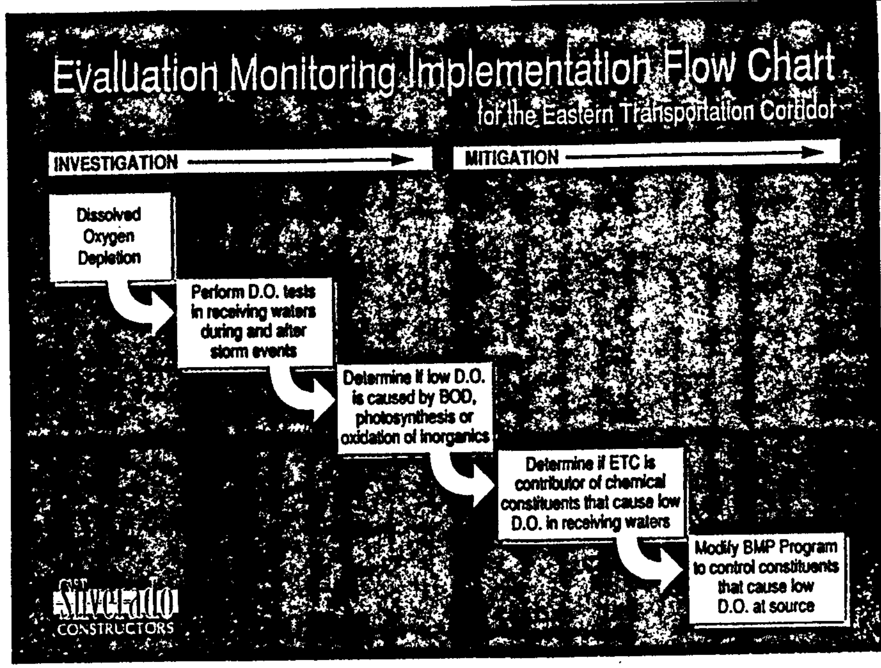
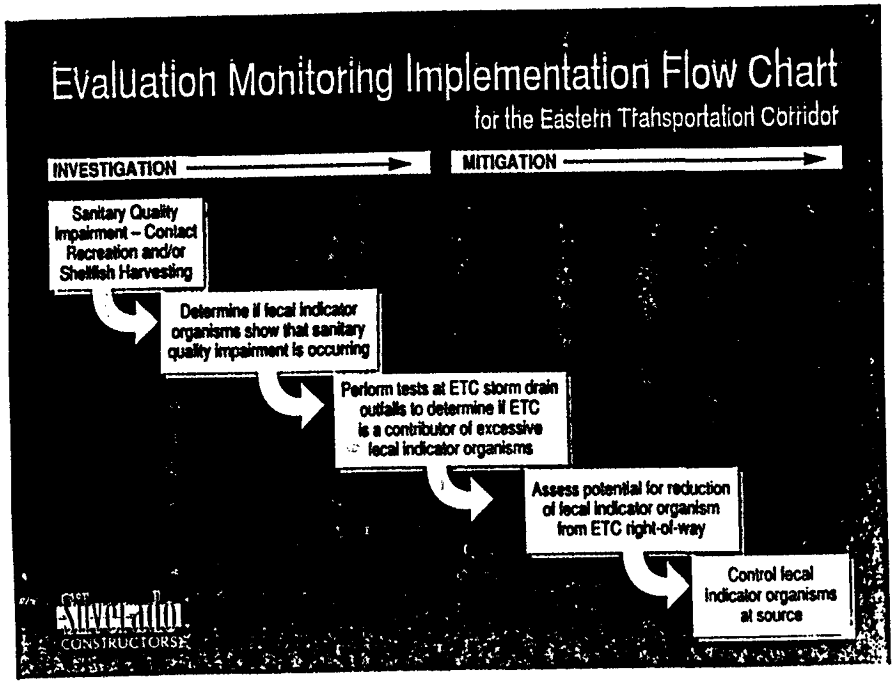
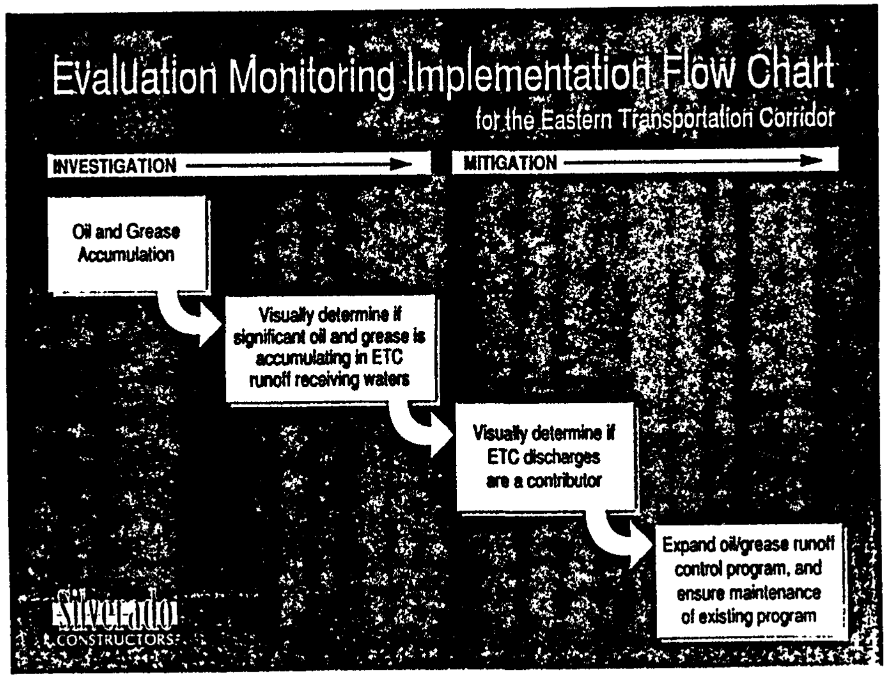
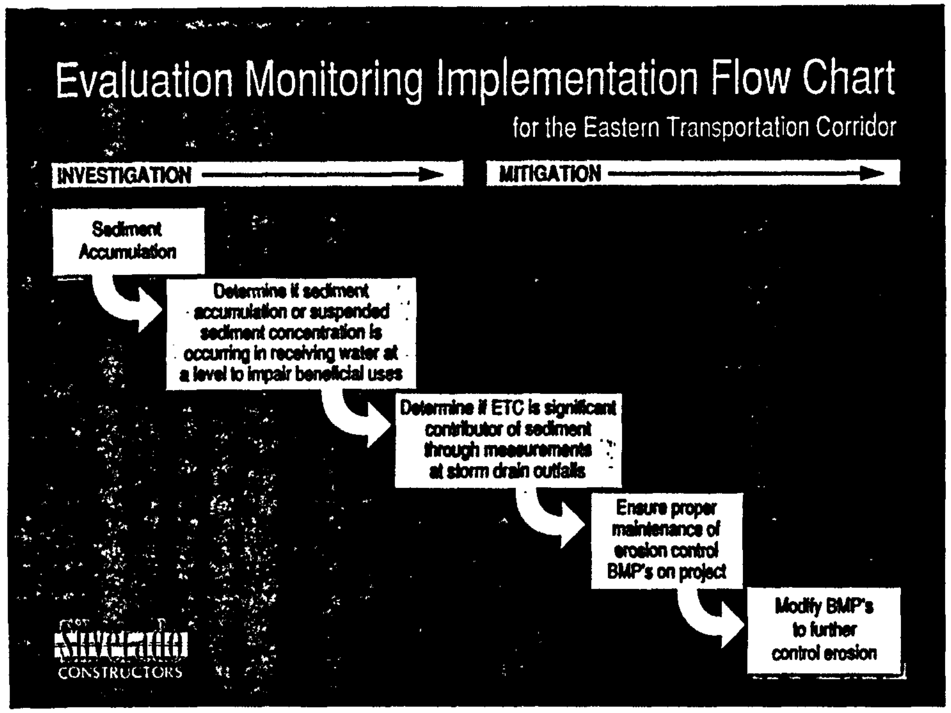

Evaluation Monitoring Implementation Flow Chart
for the Eastern Transportation Corridor
INVESTIGATION
MITIGATION
Eutrophication – Excessive Fertilization
Determine if excessive algae or aquatic weed growth occurs that impairs receiving water beneficial uses
Determine limiting nutrient – condition controlling algae biomass in the water body at time of water quality impairment concern
Determine if ETC is a significant contributor of available forms of limiting nutrient
Modify BMP Program to control available forms of nutrients at source
Silverado CONSTRUCTORS


Evaluation Monitoring Implementation Flow Chart
for the Eastern Transportation Corridor
INVESTIGATION
MITIGATION
Dissolved Oxygen Depletion
Perform D.O. tests in receiving waters during and after storm events
Determine if low D.O. is caused by BOD, photosynthesis or oxidation of inorganics
Determine if ETC is contributor of chemical constituents that cause low D.O. in receiving waters
Modify BMP Program to control constituents that cause low D.O. at source
Silverado CONSTRUCTORS


Evaluation Monitoring Implementation Flow Chart
for the Eastern Transportation Corridor
INVESTIGATION
MITIGATION
Sanitary Quality Impairment – Contact Recreation and/or Shellfish Harvesting
Determine if fecal indicator organisms show that sanitary quality impairment is occurring
Perform tests at ETC storm drain outfalls to determine if ETC is a contributor of excessive fecal indicator organisms
Assess potential for reduction of fecal indicator organism from ETC right-of-way
Control fecal indicator organisms at source
Silverado CONSTRUCTORS


Evaluation Monitoring Implementation Flow Chart
for the Eastern Transportation Corridor
INVESTIGATION
MITIGATION
Oil and Grease Accumulation
Visually determine if significant oil and grease is accumulating in ETC runoff receiving waters
Visually determine if ETC discharges are a contributor
Expand oil/grease runoff control program, and ensure maintenance of existing program
Silverado CONSTRUCTORS



Water Quality Use-Impairment Problem Identification (continued)

Drinking Water Impairment

Determine Chemical Constituents Impacting Raw Water Quality That Increase Cost of Treatment and/or Adversely Affect Finished Water Quality

Determine Sources of All Constituents That Impair Domestic Water Supply Water Quality

Bioaccumulation of Hazardous Chemicals

Determine If Edible Aquatic-Life Tissue Contains Concentrations of Hazardous Chemicals That Impair Its Use as Food

If Excessive Bioaccumulation Occurs, Determine the Significance of Runoff as a Source of the Chemical Bioaccumulating

Water Quality Use-Impairment Problem Identification (continued)

Aquatic Life Toxicity

Measure Toxicity in Runoff Water at Point at Which Runoff Enters Receiving Water and in Waterbody in Which Mixing Occurs

If Toxicity Found, Determine if of Sufficient Magnitude and Duration in Receiving Waters to Require Control

Conduct Runoff-Water Discharge-Plume Toxicity Studies
- Determine Areal Extent and Duration of Persistence of Toxicity

Use Ambient-Water Toxicity Test
- Larval Fish, Shellfish
- Assess Death, Abnormal Growth and Reproduction

If Significant Toxicity Found:
- Determine Cause through TIE Studies
- Trace Toxicity to Source

Sediment Toxicity

Determine If Sediments Are Sufficiently Toxic to Impair the Beneficial Uses of the Runoff Receiving Waters

If Significant Sediment Toxicity Exists, Determine If It Is Due to Runoff

Sanitary Quality Use-Impairment

Determine If Sanitary Quality - Fecal Indicator Organism Use-Impairment of Contact Recreation and Shellfish Harvesting Is Occurring in the Waterbody of Concern

Determine If Runoff Is Possibly a Significant Source of Fecal Indicator Organisms That Are Impairing the Use of the Waterbody for Recreation and/or Shellfish Harvesting

Water Quality Use-Impairment Problem Identification (continued)

Eutrophication - Excessive Fertilization

- Determine If Excessive Algal and/or Aquatic Weed Growth Occurs That Impairs the Uses of the Receiving Waters for Runoff

Determine Limiting Nutrient/Condition Controlling Maximum Algal/Aquatic Weed Biomass in Waterbody When Eutrophication-Related Water Quality Impairment Occurs

Determine Sources of Limiting Nutrient for the Waterbody with Particular Emphasis on the Role of Runoff as a Relative Source of N or P

Focus the Evaluation Monitoring Program on Available Forms of the Limiting Nutrient

Determine Reduction of Available Nutrient Load Needed to Achieve Improved Eutrophication-Related Beneficial Uses of the Waterbody

Dissolved Oxygen Depletion That Impairs Aquatic Life

Determine If Excessive DO Depletion Occurs in the Waterbody of Concern

If DO Problems Are Occurring, Evaluate Characteristics of Diel and Spacial DO Depletion to Determine Cause of Depletion during Times of Runoff and Non-Runoff Events

Determine If Runoff Is a Significant Contributor to the DO Depletion

Oil and Grease Accumulation

Determine If Significant Oil and Grease Accumulation Is Occurring in the Receiving Waters for Runoff

Litter Accumulation

Inspect the Receiving Waters for Runoff-Derived Litter

Siltation - Excessive Sedimentation Accumulation

Determine If Particulate/Erosional Material Is Impairing the Designated Beneficial Uses of the Receiving Waters -

Is Turbidity, Suspended Solids and/or Sediment Accumulation Altering Aquatic Life Habitat and/or Impairing Beneficial Uses of the Waterbody - Navigation - Promoting Weed Growth

For Further Information on Problems with Current Stormwater Monitoring Approach and BMP Development, as Well as on the Development of Environmental Monitoring Programs Consult the Following:

Lee, G. F. and Jones, R. A., "Suggested Approach for Assessing Water Quality Impacts of Urban Stormwater Drainage," In: Symposium Proceedings on Urban Hydrology, American Water Resources Association Symposium, November 1990, AWRA Technical Publication Series TPS-91-4, AWRA, Bethesda, MD, 139-151 (1991).

Lee, G. F., and Jones-Lee, A., "Stormwater Runoff Management: Are Real Water Quality Problems Being Addressed by Current Structural Best Management Practices? Part 1," Public Works, 125:53-57,70-72(1994). Part Two, 126:54-56 (1995).

Lee, G. F., and Jones-Lee, A., "Deficiencies in Stormwater Quality Monitoring," IN: Proc. of an Engineering Foundation Conference, American Society of Civil Engineers, New York, NY pp. 651-662 (1994).

Jones-Lee, A., and Lee, G. F., "Achieving Adequate BMP's for Stormwater Quality Management," Proceedings of the 1994 National Conference on Environmental Engineering, "Critical Issues in Water and Wastewater Treatment," American Society of Civil Engineers, New York, NY, pp. 524-531, July (1994).

Lee, G. F. and Jones-Lee, A., "Stormwater Runoff Management: The Need for a Different Approach," Water/Engineering & Management, 142:36-39 (1995). "Implementing Urban Stormwater Runoff Quality Management Regulations," Water/Engineering & Management, 142:38-41 (1995). "Issues in Managing Urban Stormwater Runoff Quality," Water/Engineering & Management, 142:51-53 (1995).

Lee, G.F. and Jones-Lee, A., "Evaluation Monitoring of Stormwater Runoff Water Quality Impacts: Initial Screening of Receiving Waters," Report of G. Fred Lee & Associates, El Macero, CA, 24pp, June (1995).

Lee, G. F. and Jones-Lee, A., "Approach for Developing BMP's to Control Pollution from Highway, Street and Urban Stormwater Runoff," Report of G. Fred Lee & Associates, El Macero, CA, 23pp, June (1995).

D-044174

Application of Evaluation Monitoring Approach for ETC Stormwater Runoff Water Quality Management

- For Each Segment of Eastern Transportation Corridor (ETC) That Drains to a Different Waterbody, i.e., Upper Newport Bay, Santa Ana River, Santiago Creek, or Irvine Lake, Review Designated Beneficial Uses of the Waterbody Relative to Composition of Highway Runoff

- For Each Designated Use, Estimate if the Stormwater Runoff from ETC Would Be Expected to Significantly Impair the Use

- If No Potentially Significant Water Quality/Use-Impairment Expected for Regulated Chemicals, Conduct Field Studies to Determine if Unregulated Chemicals Cause Water Quality/Use-Impairment

  Measure Toxicity, Bioaccumulation, Waterborne Pathogenic Indicator Organisms, Excessive Algal Blooms, Siltation, Oil and Grease, etc.

- Develop Arrangements with Regulatory Agencies and Others as Appropriate Such as OCEMA, Santa Ana Regional Water Quality Control Board, Caltrans, Orange County Water District, Serrano Irrigation District, Dept. of Fish and Game, Other Dischargers, etc. to Introduce the Evaluation Monitoring Approach and Its Implementation

- Work with Regulatory Agencies in Refining Study Program Approach, Program Implementation, Data Interpretation, and Formulation of Follow-up Studies

- Basically, Shift the Funds Normally Devoted to Monitoring Stormwater from Runoff Monitoring to Evaluation Monitoring

  Get All Stormwater and Point Source Dischargers, Regulatory Agencies, Environmental Groups and the Public to Pool Funds to Conduct Evaluation Monitoring

- Based on Funds Available/Unit Time, e.g., One Year, Prioritize Potential Water Quality Problems in Receiving Waters for Funding for Evaluation Monitoring

- May Be Necessary to Acquire Additional Funds from All Dischargers for Complex Situations

  Refine Minimum Study Program for Each Potentially Significant Impact

  If No Expected Impact and There Are Adequate Data on Overall Water Quality Characteristics of Receiving Waters, Use Funds to Confirm Applicability of Past Data on Receiving Waters

  If Adequate Data Not Available, Conduct Evaluation Monitoring to Obtain the Necessary Background Data on the Characteristics of the Receiving Waters for the ETC Stormwater Runoff

General Aspects of ETC Evaluation Monitoring Stormwater Runoff BMP Development

Evaluation Monitoring Is an Evolutional Program of Water Quality Evaluation and Management in Which the Most Important, Readily Apparent, Significant Water Quality Problems Are Addressed First to the Extent That Funds Permit

Priority for Selection of Most Significant Water Quality/Use-Impairments Has Been Determined on Initial Basis and May Be Further Refined by a Stormwater Runoff Quality Evaluation Monitoring Guidance Committee Representing Regulatory Agencies, Potentially Impacted Agencies and Entities Such as Domestic Water Supplies, Dept. of Fish and Game, Public, and Others as Appropriate

Where Real Water Quality/Use-Impairment Is Found in Receiving Waters for ETC Stormwater Runoff, Determine Cause and the Specific Source of Constituents That Cause Use-Impairment

Develop New BMPs to Control Use-Impairment Focusing on Source Control

Repeat Evaluation Monitoring Program for Each Waterbody at Least Once during Each 5-yr NPDES Permit Period

- Detect New Water Quality/Use-Impairments
- Incorporate New Information on Evaluation of Water Quality Impacts of Chemicals
- Evaluate Improvements in Receiving Water Quality Due to Implementation of Source Control BMP

Appoint a Stormwater Runoff Quality Evaluation Monitoring Technical Advisory Panel to Provide Guidance on Technical Issues

This Panel Should Consist of Individuals Who Are Familiar with the Latest Developments in the Water Quality Evaluation and Management Field with Particular Emphasis on Aquatic Toxicology, Aquatic Chemistry, Surface Water Hydrology, Point-Source Discharges to Waterbody of Concern, etc.

Silverado to Provide Framework to Work with Responsible Agencies and Interested Parties to Refine Evaluation Monitoring Approach

Start Evaluation Monitoring Implementation Approach in 1996

Use Upper Newport Bay and Santa Ana River as Focal Points for Development of Approach

Focus of Evaluation Monitoring Program

At This Time, the Focus of the ETC BMP Development Program for Upper Newport Bay Will Be on:

- Excessive Algal Growth
- Bioaccumulation
- Sanitary Quality
- Aquatic Life and Sediment Toxicity
- Litter and Oil/Grease Accumulation

For the Santa Ana River:

- Domestic Water Supply Water Quality
- Oil/Grease and Litter Accumulation

Overall Approach

Find a Real, Significant Water Quality Problem in Receiving Waters Due to ETC Stormwater Runoff, and Control Problem in Technically Valid, Cost Effective Manner

Different from Traditional "End-of-Pipe" Approach - *Yes*

In Accord with Federal & State Regulatory Requirements - *Yes*

Use of Good Science and Engineering in Public Policy Formation - *Yes*

Reduces Potential for Arbitrary, Technically Invalid Approaches - *Yes*

Implementable under Current Regulatory Requirements - *Yes*

This Approach Is Technically Valid, Cost-Effective and Far More Protective of Beneficial Uses of Receiving Waters Than Current Approach

Source Control BMP's

Brute Force - Mechanical Approach Not Appropriate

- Assume All Copper from All Sources Presumed Equally Adverse to Beneficial Uses of Receiving Water
  Ignores Aquatic Chemistry, Toxicology, Water Quality
- Auto Brake Copper/Water Quality Issue Common Ground for Environment Misdirected Effort

First: Find Real Water Quality Problem (Use-Impairment) Caused by Copper in Receiving Water

Next: Where Problem Found, Determine Specific Source of the Copper Responsible for the Use-Impairment

Then: Control Copper Appropriately at Source
If Brakepads Prove to Be the Source, Require Substitution with Material That Has Been Properly Evaluated

Conclusions

Current Water Quality Monitoring & BMP Development for Stormwater Runoff from Highways Not Technically Valid

Significant Over-Regulation of Stormwater Runoff - Wasting Public Funds

Must Shift End-of-Pipe Runoff Monitoring to Receiving Water Evaluation for BMP Development

Should Focus Financial Resources Available for Monitoring on

- Finding Real Water Quality/Use-Impairment in Waters Receiving Stormwater Runoff from Highways
- Developing Site-Specific BMP's That Control Specific Constituents Responsible for Water Quality/Use-Impairment

D—044176

Aquatic Chemistry/Toxicology in Watershed-Based Water Quality Management Programs

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Anne Jones-Lee, PhD, Vice President
G. Fred Lee & Associates, El Macero, CA

Lee, G. F., and Jones-Lee, A., "*Aquatic Chemistry/Toxicology in Watershed-Based Water Quality Management Programs,*" Proc. Watershed '96 National Conference on Watershed Management, Water Environment Federation, Alexandria, VA, pp. 1003-1006 (1996).

There is considerable discussion today about implementing the "watershed approach" for point and nonpoint sources of pollutants in a region. There is, however, considerable confusion about what is meant by the "watershed approach" in water quality management. There is even greater confusion on how the watershed approach should be implemented. U.S. EPA (Perciasepe, 1994) has adopted a Watershed Protection Approach which purports to promote integration of water quality problem solutions in surface waters, ground waters and habitats of concern on a watershed basis. According to Perciasepe, the Watershed Protection Approach is an essential priority for U.S. EPA's Water Program, however little guidance is given on how this approach is to be implemented so that it properly addresses the management of real water quality problems-designated use impairment within a watershed without significant waste of public and private funds controlling chemical constituents from point and nonpoint sources that have little or no impact on the designated beneficial uses of waters. This paper summarizes some of the issues that need to be considered in developing a technically valid, cost-effective watershed approach for managing water quality in a region focusing on the importance of properly incorporating aquatic chemistry and aquatic toxicology of chemical constituents that are to be managed in a watershed-based approach.

Implementation of the Watershed Approach

A watershed approach should be adopted where both point and nonpoint source dischargers work with the regulatory agencies to evaluate the real water quality problems in a particular waterbody. After the real water quality problems-use impairment have been identified then the specific source(s) of the specific pollutant form(s) that is responsible for use impairment should be required to control the input of the pollutants to the degree necessary to protect the designated beneficial uses of the waterbody independent of the nature of the source, i.e. point or nonpoint, agriculture, industry or urban, etc.

As discussed by Lee and Jones-Lee (1995a,b), in assessing water quality use impairment it is important not to assume that an exceedance of a water quality criterion or standard represents such a use impairment. U.S. EPA water quality criteria and state standards based on these criteria are designed to protect aquatic life and other beneficial uses under plausible worst-case or near worst-case conditions. It is indeed rare that those conditions occur. This leads to "administrative exceedances" of water quality standards that do not represent real use impairments but instead reflect the inability of the regulatory agencies to develop and implement water quality criteria and standards that will protect uses without significant over-regulation of the chemical constituents in a watershed.

It is important that those responsible for implementing the watershed approach recognize that all sources of a particular type of chemical constituent, such as copper or phosphorus, do not contribute that chemical constituent to the waterbody that impacts designated beneficial uses to the same degree per unit total concentration. Copper from automobile brake linings/pads in urban storm water runoff will be significantly different in its potential impact on receiving water quality than copper from copper sulfate used to control algae in a water supply reservoir or the copper that is used to kill roots that have penetrated a sanitary sewer system. In one case (the brake linings/pads) the copper originates as a metallic element that is unavailable and non-toxic to aquatic life. In the other cases, the specific form of copper (copper sulfate) is designed to be highly toxic to plant life. Before it is assumed that all sources of copper to a waterbody have equal adverse impacts on the beneficial uses of the waterbody proportional to the total concentration of chemical constituents, site-specific studies should be conducted to determine whether this unexpected situation is occurring. These studies would focus on the use of aquatic life toxicity testing using organisms that are known to be highly sensitive to copper.

The assumption that all sources of copper or other chemical constituents are of equal adverse impact is strongly contrary to aquatic chemistry and aquatic toxicology. Based on the authors' experience it will be indeed rare, if ever, that all sources of copper, phosphorus, or for that matter other chemical constituents, will have equal adverse impact per unit total concentration of a chemical constituent on the designated beneficial uses of a waterbody. It is, therefore, important in developing a watershed approach for water quality management to focus pollutant control on those chemical constituents that are actually significantly impairing the designated beneficial uses of the waterbody(s) within and downstream of the watershed. This is the technically valid, cost-effective approach that should be followed in implementing the watershed approach.

Pollutant Versus Chemical Constituent

Significant problems exist today in the water quality management field because of a failure to recognize the difference between *pollutants* and *chemical constituents*. Chemical constituents are any chemicals added to water, irrespective of the impact. Pollutants by tradition and national regulations are those constituents that are present in a water in sufficient concentrations of available/toxic forms for a sufficient duration to adversely impact the designated beneficial uses of the waterbody.

To assume that pollutants and chemical constituents are the same, as is sometimes done, can be and usually is highly wasteful of public and private funds in "water pollution" management programs. This will be especially true as attempts are made to control pollutants from nonpoint sources. In order to determine whether a chemical constituent is a pollutant it is necessary to develop a site-specific understanding of the aquatic chemistry and aquatic toxicology of the chemical constituent of concern as well as the key components of the designated beneficial uses of a waterbody.

Lee and Jones-Lee (1995c) have discussed that every chemical is toxic to aquatic life and man at some concentration and duration of exposure. The primary issue in water *pollution* control from various point and nonpoint sources in a particular watershed is the evaluation of the concentrations of the chemical constituents in the discharge/runoff that are, because of their chemical forms, significantly impacting the designated beneficial uses of the receiving waters for the discharge/runoff. Paulson and Amy (1993) have suggested that thermodynamic models, such as U.S. EPA's MINTEQ model, can be used to determine the toxic forms of chemical constituents in urban storm water runoff. However, such an approach is not technically valid and will, in general, greatly over-estimate the toxic forms of chemical constituents, such as heavy metals, in storm water runoff.

Pollutant Trading

As part of developing the watershed approach there is discussion of "pollutant" trading, where one source of pollutants in a watershed could be controlled to a greater degree at less cost than required based on allowed total maximum daily loads, thereby enabling another source of the same chemical constituent in the same watershed to control the chemical constituent to a lesser degree. There are a number of examples of watershed-based nutrient trading programs that have been and/or are being developed today that have significant technical problems with the way in which the "pollutant" (nutrient) trading has been established.

Hall and Howett (1994) have discussed "pollutant" (nutrient) trading in the Tar-Pamlico River Basin of North Carolina. They point out that rather than requiring point source dischargers to remove nutrients to a greater degree than currently being achieved, that the use of the funds that could be devoted to nutrient control for point source discharges could be used more effectively to control nutrients from nonpoint discharges. However, the Hall and Howett discussion fails to address one of the most important issues in eutrophication management, namely that various sources of nutrients, especially phosphorus from POTWs and agricultural land runoff, contribute algal available phosphorus to a waterbody to a significantly different degree per unit total phosphorus concentration.

This is a common, widespread problem that is occurring today with the implementation of the watershed approach where those responsible for developing such programs fail to properly incorporate reliable evaluation of the aquatic chemistry and aquatic toxicology of the chemical constituents of concern from various sources in a watershed. As discussed by Lee and Jones-Lee (1992), pollutant trading programs should be implemented where it can be shown that each of the sources of chemical constituents which are to be traded contribute chemical constituents in the same specific chemical forms and amounts to the overall waterbody of concern and thereby enable an improvement in the designated beneficial uses to develop to the same degree based on the control of the pollutant of concern from either source to the same degree. This situation will almost never occur for potentially toxic chemical constituents such as heavy metals, organics, nutrients, and other chemical constituents from point and nonpoint sources. It is highly unlikely that it will ever be possible to reliably trade pollution loads between point and nonpoint sources because of the differences in the chemical forms/impacts of most chemical constituents from these two types of sources without extensive pre-trade evaluation of the actual amounts and impacts of chemical constituents from each source of potential concern.

Another potentially significant problem with pollutant trading is that pollutants may adversely impact waterbodies in two overall ways; near the discharge and in the overall waterbody. Pollutant trading, as it is being discussed today, does not adequately consider localized adverse impacts near the discharge point on the beneficial uses of the waterbody. Local impacts on large waterbodies can be quite significant to the public that utilizes the beneficial uses of the waters near the point of discharge. This point is discussed further by Lee and Jones-Lee (1994a) in evaluating the economic aspects of pollutant trading.

Control of Chemical Constituents at Source-Pollution Prevention

One of the frequently advocated components of a watershed management approach is pollution prevention, i.e. the control of chemical constituents at their source. One of the major areas of concern in regulating urban storm water runoff and other sources of chemical constituents for a waterbody is the presence of elevated concentrations of a number of heavy metals and other chemical constituents in the storm water runoff/discharges that are potentially controllable at the source. Copper is one of the elements of greatest concern in urban storm water runoff. Copper and many other heavy metals are present in urban storm water runoff at concentrations considerably above U.S. EPA water quality criteria. It has been found that one of the principal sources of copper is its use in brake linings/pads for some types of automobiles. This has led some to call for copper source control by requiring that the manufacturers of brake linings/pads stop using copper where some other material would be substituted for the copper that is being used today. Numerous studies have shown, however, that the heavy metals, including copper, in urban storm water runoff are not a source of toxicity to aquatic life (see Mangarella, 1992).

There are significant questions, therefore, about whether voluntary or imposed national or regional bans on the use of copper in brake linings/pads is an appropriate best management practice for storm water runoff water pollution control. While adoption of this approach would likely reduce some of the administrative exceedances of copper at some locations, such as for San Francisco Bay, it would not likely address any real water quality problems (use impairment) associated with the presence of copper in storm water runoff to the Bay or its tributaries. Further, since some other material will have to be substituted for copper, concern should be raised on the potential public health and environmental impact of the substitute material.

In formulating a point and nonpoint source chemical constituent control program, it is important to reliably evaluate the aquatic chemistry and aquatic toxicology of the chemical constituents that are to be controlled through best management practices. It is also important to understand that the current suite of structural best management practices, such as detention basins, grassy swales, etc., were not based on a technically valid assessment and that their implementation would solve real water quality problems (Lee and Jones-Lee, 1996). An example of this situation is the use of detention basins where low flow storm waters are retained in a basin for a period of time where large particulate forms of chemical constituents settle out. However, particulate forms of chemical constituents are generally non-toxic and non-available to aquatic life. Detention basins typically do not remove the soluble/toxic forms of chemical constituents. Lee and Jones-Lee (1995c) have discussed the importance of properly selecting best management practices for chemical constituent control in a watershed, including control at the source, so that the control focuses on addressing real water quality problems rather than wasting public and private funds controlling chemical constituents which have little or no impact on the beneficial uses of the waters in the watershed.

Conclusion

Water pollution control programs should be based on a watershed management-based control program in which all chemical constituent sources to a waterbody are reliably evaluated as to their potential impact on the designated beneficial uses of a waterbody. The focus of the watershed approach should be on protection and, where degraded, enhancement of the designated beneficial uses of the waterbody. For aquatic life-related uses, the focus should be on the numbers, types, and characteristics of desirable aquatic organisms. The mechanical approach that is being adopted today in some watershed approaches for water quality management of considering all chemical constituents from all sources of equal impact on the designated beneficial uses per unit total chemical constituent concentration derived from the source is technically invalid. In implementing the watershed approach, proper evaluation of the chemical constituent aquatic chemistry and aquatic toxicology as it may impact the designated beneficial uses of a waterbody must be made in order to avoid waste of public and private funds in controlling chemical constituent inputs that are not adversely impacting water quality within the watershed and downstream thereof.

Pollutant trading should be based on the trading of real pollutants, i.e., those that impact designated beneficial uses at a particular location in a waterbody. Consideration should be given to waterbody-wide effects as well as those that can occur near the point of discharge/runoff.

References

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Aquatic Chemistry/Toxicology in Watershed-Based Water Quality Management Programs

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G. Fred Lee & Associates

El Macero, California

Presented at:
Water Environment Federation Conference, *"Watershed '96"* Baltimore, MD, June 1996

Watershed Approach for Water Quality Management

What Should a Watershed Based Water Quality Management Approach Involve?

All Stakeholders Working Together to Identify, Prioritize and Manage All Significant Water Quality Problems in a Waterbody and Its Tributaries

Broaden the Scope of Water Pollution Control to Address All Impairment of Uses and All Sources of Pollutants that Impair Uses

Ag No Longer Exempt from Practicing Full Water Pollution Control

Consider Both Near-Field (Near Point of Discharge-Runoff) and Far-Field (Waterbody-Wide) Impacts

Definitions

Water Quality - Impairment of Designated Beneficial Uses: Fish and Aquatic Life, Domestic Water Supply, Wildlife Habitat, Contact Recreation, Etc.

Chemical Constituent - A Chemical Added to or Present Within Water

Pollutant - A Chemical Constituent That Impairs the Beneficial Uses of a Waterbody

Chemical Constituent ≠ Pollutant

Most Chemicals Exist in a Variety of Chemical Forms, Only Some of Which Are Toxic - Available to Impact Water Quality

Waterbody - Water Column Including the Sediments

Watershed is the Area That Contributes Water to a Waterbody; Includes Airshed - Atmosphere and Groundwater

Deficiencies in Current Watershed-Based Water Quality Management

Current Watershed Approach for Water Quality Management Largely Ignores Aquatic Chemistry and Toxicology - Real Water Quality Issues

Brute Force Approach

Assumes That All Forms of Chemical Constituents Equally Important

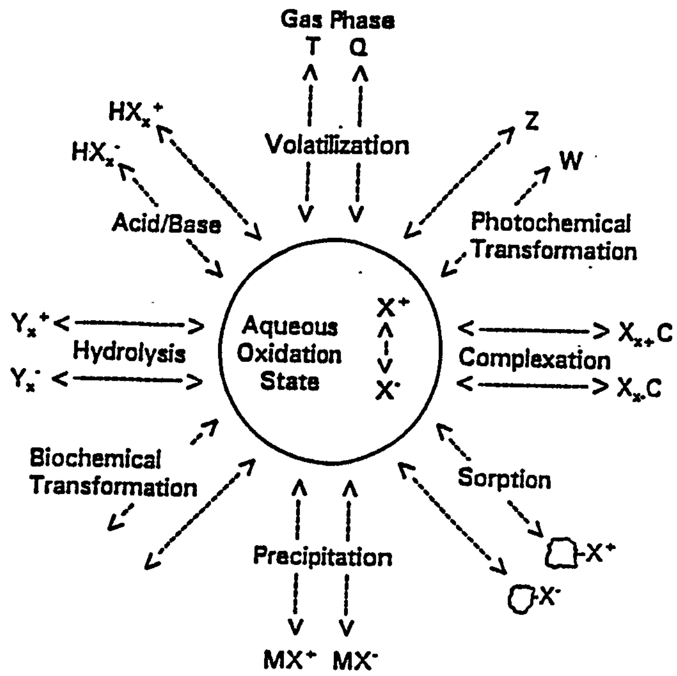
All Copper, Mercury, Other Heavy Metals, Pesticides, PCBs, Phosphate Are in Forms That Adversely Impact Water Quality
Well Known Not To Be True

Assumes All Aquatic Organism Exposure a Chronic Exposure

Aquatic Toxicology - Adverse Impacts Such as Toxicity, Excessive Bioaccumulation, Tumors, Etc.

Aquatic Chemistry - Chemical Transformations; Kinetics (Rates) and Thermodynamics (Energy - Equilibrium)

Aquatic Chemistry of Chemical Contaminants



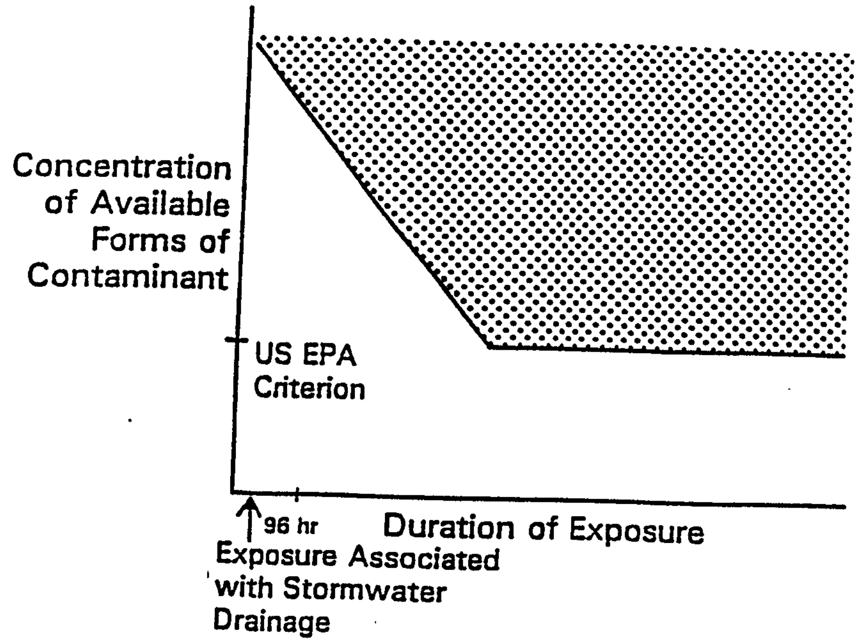
Distribution Depends on Kinetics & Thermodynamics of Reactions in a Particular Aquatic System

Each Chemical Species Has Its Own Toxicity Characteristics

Many Forms Are Non-Toxic

Toxic Forms Are Typically Aqueous Aquo-Species of Metals

Aquatic Toxicology



US EPA Criteria List 1-hr-Average Maxima and 4-day-Average Maxima

Not Valid for Assessing Potential Impacts of Urban Stormwater Drainage

What Makes a Chemical Constituent Deleterious to Water Quality - Beneficial Uses?

Aquatic Toxicology and/or Bioaccumulation
- Organism Sensitivity to Potential Adverse Impacts
  - Acute and Chronic Toxicity
- Duration of Exposure

Aquatic Chemistry
- Chemical Reactions That Determine the Composition and Specific Chemical Species Present
- Factor Controlling Composition and Changes in Composition
- Kinetics (Rates) and Thermodynamics (Energy - Equilibrium)

Technically Appropriate Use of Water Quality Criteria and Standards

US EPA Water Quality Criteria and State Standards Numerically Equal To These Criteria Are Based On Worst-Case or Near Worst-Case Assumptions With Respect To Impacts On Aquatic Organisms

- Chronic Exposure to 100% Available Forms
- Rarely Will These Conditions Occur

Not To Be Exceeded For More Than Once In Three Years At the Edge Of Mixing Zone

- Leads to Significant Over-Estimation of Both Near-Field and Far-Field Impacts

Chemical Specific Water Quality Criteria and State Standards Should Be Used to Indicate Potential Adverse Impacts

- Allow Discharger and the Public To Determine If Exceedance Of Standards Represents a Real Impairment of Water Quality
  - Impairment of Uses or an Administrative Exceedance

Human and Ecological Risk Assessment: Vol. 1, No. 1, pp. 5-11, 1995

Appropriate Use of Numeric Chemical Concentration-Based Water Quality Criteria

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D—044183

INTRODUCTION

Increasing attention is being given to the cost-effectiveness of chemical contaminant control programs established to reduce toxicity to aquatic life in the watercolumn and sediment, and excessive bioaccumulation of contaminants in aquatic life. Evaluation and control of chemical contaminants has generally focused on either the effects of the contaminant(s) on aquatic organisms (biological effects-based approaches), or on concentrations of individual chemical contaminants with extrapolations to their impact on aquatic organisms (chemical concentration-based approaches).

Owing to their comparative simplicity and ostensible ease of application, chemical concentration-based state water quality standards based on or equivalent to US EPA numeric water quality criteria are being increasingly relied upon as independently applicable regulatory tools for the assessment, protection, and/or enhancement of designated beneficial uses of aquatic systems. However, the present-day use of such criteria and standards largely ignores the aqueous environmental chemistry and toxicology of contaminants, the worst-case or near-worst-case foundation of those criteria, and the fact that there is a large body of contaminants for which numeric concentration criteria do not exist. Each of these factors diminishes the reliability of the extrapolation of chemical concentrations to impacts on aquatic organisms/beneficial uses of water, and tends to make them more stringent than necessary to protect designated beneficial uses of waters. That notwithstanding, the US EPA has adopted the policy of Independent Applicability for chemical concentration criteria in which chemical-specific concentration values are applied independent of biological effects-based approaches for regulating "water quality". They are presumed to be independently reliable even when they indicate an "effect" that is not supported by biological effects-based approaches, such as toxicity testing and actual measurements of bioaccumulation evaluated on a site-specific basis.

Inappropriate Regulatory Approaches

US EPA Independent Applicability Policy

- Contrived to Ease Administration of Water Quality Standards Technically Invalid

- Requires Compliance With Chemical Specific Standards For Potentially Toxic or Bioaccumulatable Chemicals Even if Site-Specific Investigations Show That the Constituents Of Concern Are in Non-Toxic Forms and Excess Bioaccumulation is Not Occurring

  - Leads to Gross Over-Regulation and Potentially Massive Waste of Public Funds in Regulating Urban Area, Highway and Rural Stormwater Runoff

  - Must Focus Watershed Approach for Water Quality Management On Toxic Available Forms Where Toxicity and Actual Bioaccumulation Are the Primary Tools Used for Defining Water Quality Impacts

Independent Applicability Policy Should Be Terminated

Independent Applicability of Chemical and Biological Criteria/Standards and Effluent Toxicity Testing

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5(1):60-63 (1995)

In 1985 the U.S. Environmental Protection Agency (EPA) advocated a two-part approach for water pollution control involving chemical concentration-based effluent limits for those parameters for which water quality criteria had been developed and toxicity test-based effluent limitations. The chemical-specific component was designed to prevent exceedances of water quality criteria values in ambient waters receiving point and non-point source discharges or runoff; the water quality criteria were, in large part, developed to be chronic-exposure, safe concentrations for sensitive aquatic organisms. The toxicity test component was designed to indicate potential toxicity effects associated with an activity, to account for the possible presence of a toxic contaminant that did not have a water quality criterion, and to provide the opportunity for site-specific tuning of the chemical-specific criteria for synergism, antagonism, chemical availability, and exposure situations.

EPA has since expanded its recommended approaches to include a direct measure of biological characteristics (biological criteria) of surface waters. The biological criteria focus on the numbers, types and characteristics of organisms present downstream of a discharge or runoff compared with the numbers, types and characteristics expected based on the aquatic life habitat characteristics. A number of states have developed biological criteria and have been using them in water pollution control programs.

At a 1992 EPA workshop on water quality criteria and standards, EPA representatives revealed that the Agency would soon be releasing a position paper announcing the policy of "Independent Applicability." The June 1992 issue of EPA's "Newsletter Water Quality Criteria & Standards," however, stated that Independent Applicability is EPA's present position, and it is detailed in several documents. That inconsistency notwithstanding, the policy and/or practice of independent applicability and its ramifications for water pollution control in the country truly deserves a thorough examination.

The Problem with Independent Applicability

According to EPA in 1992, the three above-mentioned regulatory approaches for the regulation of toxics would be applicable to all waters, and the approach that was most "sensitive," (most limiting) for a particular waterbody would guide management. This led to many questions about how the policy would handle a situation in which:

- Biological studies of the receiving waters showed healthy and wholesome fish and other aquatic life populations, the same as those that would be expected based on habitat characteristics, and
- Short-term chronic toxicity testing of the waters in the region showed no aquatic life toxicity, but
- Numeric water quality criteria (or standards equivalent to them) were exceeded.

At that time, EPA stated that even under such circumstances, the discharger or source of runoff would have to implement control programs to eliminate the exceedances of the water quality criteria or standards, or change the standards. It was reported to be EPA's position under the policy of independent applicability to require that site-specific water quality criteria or standards be developed in order to justify not complying with EPA's water quality criteria, or more properly, state standards equivalent to those criteria.

It is appropriate to question the appropriateness of requiring dischargers and state regulatory agencies to develop site-specific water quality standards in response to that scenario (i.e., a situation in which it had been shown that there was no aquatic life toxicity in the receiving waters for the discharge/runoff and the populations of aquatic life in the region of expected impact were what would be expected based on habitat characteristics). There have been few attempts to develop site-specific water quality standards as outlined in EPA's Water Quality Criteria Handbook. As a consequence of the state of California Water Resources Control Board's adoption of EPA criteria as state water quality objectives (standards) in April 1991, a number of studies have been undertaken in California in an effort to develop site-specific objectives. More than $300,000 were spent in such effort in the San Francisco Bay area; more than $1.1 million were spent in efforts to develop site-specific criteria/standards for the Santa Ana River in southern California. However, as discussed below, the funds spent in trying to develop site-specific water quality objectives for copper in San

Watershed Approach for Managing San Francisco Bay Copper
A Watershed Approach Gone Awry

Exceedance of National Copper Water Quality Standard - 2.9 μg/L

Developed Site-Specific Standard Based on Water Effect Ratio Approach - 4.9 μg/L

Find 10 to 15 μg/L Soluble Copper in San Francisco Bay Waters

Because of Independent Applicability Must Develop Waste Load Allocation and Total Maximum Daily Loads (TMDLs)

"Phased Approach" Adopted Because of a Lack of Understanding of the Relationship Between Copper Loads and Copper Concentrations in Bay Waters

Phase I - All Dischargers Reduce Total Copper Loads by 20%

Copper Sources For South San Francisco Bay: Treated Wastewaters 15%, Auto Brakepads 35%, Other Runoff Sources - Urban and Highway Stormwater and Mine Waste 50%

Each Source of Copper Must Reduce Copper Input to Achieve TMDLs

All Sources of Copper Considered Equally Harmful

Ignored the Role of Bay Sediments as a Source of Copper to the Water Column During Storms

If All Copper Inputs From the Watershed Terminated, the Soluble Copper Concentrations in the Bay Will Be Exceeded for More Than Once in Three Years, *i.e.*, Will Still Have Exceedance of Water Quality Standards

Phased Approach Technically Invalid Must Have an Understanding of the Relationship Between Copper Loads and the Resultant Concentrations Also Must Consider Sediments in Evaluating Exceedance of Water Quality Standards

All Sources of Copper Are Not of Equally Toxicity

Cu - Metal - Some Auto Breakpads
Cu^{2+}, $Cu(H_2O)_6^{2+}$
$CuOH^+$, $Cu(OH)_2$, $CuCO_3$
CuO, $CuCO_{3s}$
Cu organic, Cu-humates, Cu-EDTA, Etc.

Models - MINTEQ Not Reliable to Predict Toxic Forms

Soluble Copper - Some Non-Toxic

Must Use Toxicity Measurements and TIEs To Determine If Copper In a Water Sample Is Toxic

Watershed Approach for Managing San Francisco Bay Copper
Where Is The Problem?

Extensive Toxicity Measurements of San Francisco Bay Waters Over Three Years Have Shown No Toxicity Due to Copper or Other Constituents to Several Highly Sensitive Aquatic Organisms

Used the Same Organism and Test as Was Used to Establish the Water Quality Criterion - No Toxicity Found

Exceedance of the Water Quality Standard is an Administrative Exceedance Due to Overly Protective Standard (Worst-Case) and Inappropriate Regulatory Approach (Independent Applicability)

Could Cause Stormwater Dischargers (Municipalities) to Spend Over One Billion Dollars Treating Urban Area and Highway Stormwater Runoff to Achieve Copper Water Quality Standard in Bay Waters

No Beneficial Uses of the Bay are Expected to Result From Such Expenditures

Example of Inappropriate Watershed Approach That Fails to Properly Incorporate Aquatic Chemistry and Toxicology

D-044185

Santa Monica Bay Stormwater Runoff

- Santa Monica Bay Restoration Project Adopted the Watershed Approach for Managing 22 Chemicals That are Transported into Santa Monica Bay in Stormwater Runoff
  - Heavy Metals Focal Point of Attention
  - Mass Load Emission Strategy Adopted
    - All Stormwater Runoff Sources of Metals Considered Toxic and Available - No Measurements Made to Verify Assumptions

Heavy Metals Accumulate in Near-Shore Sediments of Santa Monica Bay - Assumed That Elevated Concentrations of Heavy Metals in Sediments Represents Significant Adverse Impacts to Beneficial Uses of Santa Monica Bay Due to Aquatic Life Toxicity

- No Toxicity Measurements Made

Require Expenditure of $42 Million Over Five Years to Control Heavy Metal and Other Constituent Inputs to Santa Monica Bay From Watershed (Including City of Los Angeles and Surrounding Communities)

- Implementation of Stormwater "BMPs"
  - Assume That Any Approach That Removes Heavy Metals in Stormwater Runoff is a BMP for Protection of Santa Monica Bay
    - Technically Invalid Approach
    - A BMP for Stormwater Runoff is Valid if it Improved Beneficial Uses of Receiving Waters
    - Heavy Metals in Stormwater Runoff from Urban Areas and Highways Are in Non-Toxic, Non-Available Forms Also Rarely Will Heavy Metals From These Areas Be Adverse to Aquatic Life When They Accumulate in Receiving Water Sediments

Pollutant Trading

Under TMDL Situations, Dischargers Are Required to Control a "Pollutant" to a Specified Load

- Some Sources Can Control the Pollutant at Less Cost Per Unit Mass of Pollutant Removed Than Others
- The Discharger Which Can Most Cost-Effectively Remove Pollutants Do So and Thereby Allow Another Discharger to Remove Less of Their Pollutant Load

In a True Pollutant Trading Situation Must Trade Pollutants That Impact Water Quality Not Chemical Constituents Irrespective of Their Impact

- Consider Near-Field and Far-Field Effects
- Evaluate Toxic-Available Forms

Pollutant Trading For Control of Toxicity

Metals and Some Organics Are Of Concern Because of Potential Toxicity or Bioaccumulation

Should Trade Toxic Units Not Total Metals or Even Dissolved Metals

Should Trade Bioaccumulatable Forms Not Total Concentrations

Technically Valid Pollutant Trading Will Require Site-Specific Evaluation of Each Major Source of Constituents of Concern To Determine the Pollutant Content

Management of Eutrophication

Eutrophication - Excessive Fertilization One of the Most Important Causes of Water Quality - Use Impairment in the US

- Excessive Growth of Algae and Other Aquatic Plants
- Most Freshwater Waterbodies Algal Growth Controlled by Phosphorus
- Nitrogen Important For Most Estuarine and Marine Systems and Some Freshwater Systems Especially on the West Coast

Watershed Approach to Eutrophication Management Focusing on Controlling Limiting Nutrient Input Often Technically Invalid

- Ignores the Aqueous Environmental Chemistry of Phosphorus
- The Total Phosphorus Load From Some Sources is a Poor Predictor of Algal Available Phosphorus
  - Only About 20% of the Particulate Phosphorus in Urban Area and Rural Runoff Available to Grow Algae

Pollutant Trading For Eutrophication Control

Phosphate From Non-Point and Point Sources Are Not Pollutants To the Same Degree

POTW Residual Phosphorus May or May Not Be Available to Support Algal Growth

- Aluminum and Iron Treatment For Phosphate Removal Produces Particulate Iron or Aluminum Phosphates
- Filter Effluent to Further Remove Particulates
  - Removing Non-Algal Available Phosphorus
- Non-Point Sources - 80% of the Particulate Phosphorus Non-Available to Support Algal Growth

Must Trade Algal Available Phosphorus Not Total Phosphorus

Water Quality Issues in Pollutant Trading[1]

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Abstract

As part of implementing the watershed approach for water pollution control, interest is being focused on pollutant trading. The pollutant trading programs that have been developed thus far are based on total chemical constituent concentrations and fail to properly consider that for many chemical constituent sources and types of chemical constituents the total chemical constituent concentration in a source or within the waterbody is a poor measure of potential water quality impacts. Pollutant trading should be based on trading chemical constituents that are adversely impacting the designated beneficial uses of a waterbody, i.e. cause pollution, rather than the total chemical constituent concentrations within the various sources for which trades are being considered.
(KEY TERMS: pollutant trading; point/nonpoint source; water quality criteria/standards; water quality.)

Introduction

Malik *et al.* (1994) have discussed economic aspects of pollutant trading as part of their discussion of economic issues of the watershed approach for water quality management. This discussion, however, fails to consider important often overriding water quality issues that should be addressed in any pollutant trading activity. A fundamental deficiency in most pollutant trading programs that have been proposed is the failure of those involved to recognize the difference between pollutants and chemical constituents. Basically, Malik *et al.* have discussed chemical constituent trading. It is important in any water quality management program to clearly distinguish between those forms of chemical constituents that are present in a waterbody or its inputs which give rise to a total concentration in the waterbody and those that are present in chemical-specific forms that adversely impact the designated beneficial uses of the waterbody.

Chemical Constituents vs. Pollutants

Chemical constituents exist in aquatic systems in a variety of chemical forms, only some of which are toxic-available (see Lee *et al.*, 1982). For the purposes of this discussion and in accord with traditional approaches, "chemical constituents" are defined as those chemicals which are present in a waterbody or input irrespective of whether they are in chemical forms that adversely impact the designated beneficial uses of the waterbody. "Pollutants," on the other hand, are those chemical constituents that are present in sufficient concentrations of available-

[1]Submitted for publication in Water Resources Bulletin, February (1996).

Purpose of Water Quality Monitoring

- Define Water Quality Impacts of Stormwater Runoff
- Serve as a Basis for BMP Selection
- Establish Basis for Pollution Source Control
- "Compliance" with NPDES Discharge Limits

egulatory Requirements

Purpose - To Control Stormwater Runoff Caused Pollution - Use Impairment to MEP Using BMPs

US EPA Proposed Policy - Must "Achieve" Water Quality Standards in the Receiving Waters. However, Exceedance of these Standards Does Not Constitute an NPDES Permit Violation
No Need for Traditional End-of-the-Pipe Compliance Monitoring

Need for Alternative Approach

Urbanos and Torno in the overview summary of the Stormwater NPDES Related Monitoring Needs, Engineering Foundation Conference, August 1994,

"If we are to acquire this understanding, we must stop wasting monitoring resources on the 'laundry list' type of monitoring encouraged or required by our current regulations. We must instead move towards well-designed and adequately funded national and regional scientific study programs and research efforts."

Davies in Proceedings Engineering Foundation Conference "Stormwater Runoff and Receiving Systems: Impact, Monitoring and Assessment," 1995

"It is generally agreed that NPS [nonpoint source] *problems are unique and complex, and they will not be resolved as easily as the relatively simple treatment and standard compliance approaches used in the PS* [point source] *program. NPS programs will require development and application of innovative and imaginative control strategies, and the program will cost much more than the PS program."*

D-044187

US EPA May 3 Draft Interim Stormwater Runoff Permitting Approach

"In order to gather necessary information about storm water discharges, storm water permits should include coordinated and cost-effective monitoring programs, such as ambient monitoring, receiving water assessment, discharge monitoring (as needed), or a combination of monitoring procedures designed to gather necessary information."

"The amount and types of monitoring necessary will vary depending on the individual circumstances of each storm water discharger. EPA encourages dischargers and permitting authorities to carefully evaluate monitoring needs and storm water program objectives so as to select useful and cost-effective monitoring approaches. For most dischargers, storm water monitoring can be conducted for two basic reasons: 1) to identify if storm water problems are present, either in the receiving water or in the discharge, and to characterize the cause of those problems; and 2) to assess the effectiveness of storm water controls to reduce contaminants and make improvements in water quality."

Focus of Recommended Monitoring Programs on Receiving Water Characterization Using:

"Techniques that assess receiving waters will help to identify if storm water problems are present, where these are not known. Techniques that assess storm water discharge characteristics will help to identify potential causes of any identified water quality problems."

"Although municipal NPDES storm water permit applications emphasized end-of-pipe chemical-specific storm water monitoring, this type of monitoring does not need to be repeated during the term of the permit if it is not identified as the best monitoring tool to support the purpose of the municipality's storm water management program."

Evaluation Monitoring For Implementation of a Watershed Based Water Quality Management Program

Current Water Quality Monitoring Programs are Largely End-of-the-Pipe Edge-of-the-Pavement/Property "Compliance" Monitoring

Provide Little to No Useful Information on the Real Water Quality Use Impairments That Are Occurring in the Receiving Waters For the Discharge - Runoff

Evaluation Monitoring Developed to Use Monitoring Funds More Appropriately to Define Real Water Quality Use Impairments in the Receiving Waters For the Discharge - Runoff

Shift Monitoring Emphasis From Discharge - Runoff to Receiving Waters

All Dischargers, Regulatory Agencies and the Public Work Together to Use Monitoring Funds Available to Find Real Water Quality Use Impairments in a Waterbody

Where Such Use Impairments Are Found, Assess and Prioritize Their Significance

Potential Water Quality Problems That Should Be Considered in a Watershed Based Water Quality Management Program

Aquatic Life Toxicity - Water Column and/or Sediments

Excessive Bioaccumulation of Hazardous Chemicals

Domestic Water Supply for Surface and Groundwaters

Sanitary Quality - Contact Recreation and Shellfish Harvesting

Eutrophication - Excessive Fertilization

Petroleum Hydrocarbons - Oil and Grease

Aquatic Life Carcinogens

Oxygen Demand

Sediment Accumulation - Siltation, Turbidity, Navagation, Habitat

Litter and Debris

Evaluation Monitoring Approach (continued)

Problem Definition and Control

Determine the Cause and the Source of Constituents Responsible for the Use Impairment

Develop Site-Specific Programs That Will Control the Use Impairment to the Maximum Extent Practicable

Repeat Evaluation Monitoring Program Evaluation of Each Potential Water Quality Use Impairment Every Five Years to Detect Changes in Activities Within the Watershed That Are or Could Be Adverse to the Waterbodies Water Quality

Also to Detect New or Increased Use of Constituents That Impair the Beneficial Uses of a Waterbody Introduced Into the Watershed

Overall, Evaluation Monitoring Focuses on Finding a Real Water Quality Problem in a Waterbody, Determining Its Cause and Significance and Developing Control Programs For Controlling the Input of Pollutants at the Source

Assessing Water Quality Impacts of Stormwater Runoff[1]

G. Fred Lee, PhD, PE, DEE (Member)[2]
Anne Jones-Lee, PhD (Member)

__Abstract__

Current "water quality" monitoring of non-point source runoff typically involves periodically measuring a laundry list of chemicals in the runoff waters. This approach, while satisfying regulatory requirements, provides little to no useful information on the impact of the chemicals in the runoff on the real water quality - designated beneficial uses of the receiving waters for the runoff. There is need to focus water quality monitoring on investigating the receiving waters in order to assess whether the chemicals in the runoff are adversely affecting beneficial uses. This paper presents an evaluation monitoring approach for monitoring receiving waters that determines whether the runoff is a significant cause of water quality - use impairments. For each type of use impairment, such as aquatic life toxicity, excessive bioaccumulation of hazardous chemicals, excessive fertilization, etc., highly focused site-specific studies are conducted to determine the use impairment that is likely occurring due to a stormwater runoff event(s) and the specific cause of this impairment.

Key words: stormwater, water quality, monitoring, highway

__Introduction__

There is growing recognition that domestic and industrial wastewater and stormwater runoff "water quality" monitoring involving the measurement of a suite of chemical "pollutant" parameters in discharge/runoff waters is largely a waste of money. For stormwater runoff, such programs generate more data of the type that have been available since the 1960's on the chemical characteristics of urban area, highway and street runoff. It has been known since that time that runoff from these areas contains a variety of regulated chemical constituents and waterborne pathogenic organism indicators that exceed water quality standards at the point of runoff discharge to the receiving waters. However, discharge monitoring provides little to no useful information on the impacts of the apparently excessive regulated chemicals and unregulated chemicals in the discharge on receiving water water quality - designated use impairment. As discussed by Lee and Jones (1991) and Lee and Jones-Lee (1994a, 1995a,b), many of the chemical constituents in urban stormwater runoff are in particulate, non-toxic, non-available forms. Further, the short-term episodic nature of

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[1]Invited paper to be presented at the American Society of Civil Engineers North American Water and Environment Congress '96 to be held in Anaheim, CA, June 1996.

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Evaluation Monitoring for Stormwater Runoff Monitoring and BMP Development

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Abstract

This report covers the development and application of evaluation monitoring to highway, urban area and street stormwater runoff water quality management. A discussion is presented on the need for an alternative approach to the conventional approach of evaluating the water quality impacts of highway and urban area stormwater runoff on receiving water quality. Information is presented on the background to the development and application of site-specific studies (evaluation monitoring) that are conducted on the receiving waters for stormwater runoff that identify real water quality use impairments in these waters that are caused by chemical constituents and/or pathogenic organism indicators in the stormwater runoff.

The evaluation monitoring program is designed to replace the conventional "water quality" monitoring programs that are used for measuring the chemical constituents in highway, urban area and street stormwater runoff. It is widely recognized that conventional runoff water quality monitoring provides little in the way of useful information that can be used to evaluate the impact of stormwater runoff on the beneficial uses of the receiving waters for the runoff. Evaluation monitoring serves as a technically valid, cost-effective basis for BMP development that replaces the conventional approach that is used to develop stormwater runoff water quality BMPs. The conventional BMP development approach assumes that detention basins, grassy swales, various types of filters, etc. are effective BMPs in controlling real water quality use impairments due to heavy metals, organics and other constituents in highway and urban area stormwater runoff. However, it is now well-known that particulate forms of heavy metals and other constituents that are removed in conventional stormwater runoff BMPs do not adversely impact the beneficial uses of the receiving waters for the runoff. The particulate forms of heavy metals and other constituents are in non-toxic, non-available forms. Therefore, their removal in a detention basin will not be of benefit to the beneficial uses of the receiving waters for the stormwater runoff.

Basically, the evaluation monitoring program shifts the funds that are used for end-of-the-pipe runoff monitoring to site-specific, highly directed studies designed to find real water quality use impairments of the receiving waters for the stormwater runoff. When such use impairments are found that are due to highway, urban area or street runoff, then BMPs are developed that control the input of the pollutants, i.e. those constituents that cause impairment of the beneficial uses of the receiving waters for the stormwater runoff to the maximum extent practicable. The

Chemical Constituent vs. Pollutant

Must Clearly Distinguish Between Those Chemical Constituents Which Are Important in Adversely Affecting the Beneficial Uses of a Waterbody
Must Be Evaluated on a Site-Specific Basis

Selection of BMP's

Objectives: Control Impairment of Waterbody Uses of Concern to the Public in a Technically Valid, Cost Effective Manner
Err Slightly on the Side of Protection
Protect and Enhance without Wasting Large Amounts of Public and Private Funds

Evaluation of the Efficacy of BMP's

Current Approach
Across Structural BMP or Before and After Chemical Input Control
Not Technically Valid Focuses on Chemical Constituents Not Pollutants

Valid Approach

Must Focus BMP Efficacy Evaluation on Receiving Waters Changes in Beneficial Uses
Not the Same as Chemical Constituent Changes

Development of Technically Valid Watershed Approach for Water Quality Management

- Organize All Stakeholders (Dischargers, Water Users, Interested Parties, Regulatory Agencies, Etc.) to Develop Watershed Based Water Quality Management Approach

- Appoint a Stakeholders Technical Advisory Committee That Includes Several Individuals Knowledgeable in Aquatic Chemistry, Aquatic Toxicology and Water Quality

- For Each Potential Type of Water Quality Use Impairment Within the Waterbody of Concern, Assess What is Known About Its Magnitude and Significance Within the Waterbody and Downstream Thereof

- Develop a Data-Information Gathering Program to Fill Data Gaps on Current Water Quality Problems Within the Waterbody

Is There Aquatic Life Toxicity in the Ambient Waters?

Do Fish and Other Aquatic Life Have Excessive Concentrations of Bioaccumulatable Chemicals?

Is There an Impairment of Contact Recreation or Shellfish Harvesting Due to Excessive Concentrations of Fecal Indicator Organisms?

Is The Use of Water For Domestic Water Supply Purposes Impaired? - Consider Both Surface and Groundwater

Is There Excessive Growth of Algae and Other Aquatic Plants?

Are the Sediments Toxic to Aquatic Life?

Do the Sediments Serve as a Source of Bioaccumulatable Chemicals That Impair the Beneficial Uses of the Waterbody?

Do Low Dissolved Oxygen Conditions Exist in the Waterbody?

Is There Excessive Trash and Other Debris, Oil and Grease, Etc.?

(continues)

D—044190

Development of Technically Valid Watershed Approach for Water Quality Management (continued)

- The Stakeholders - the Public Should Prioritize the Water Quality Use Impairments Within the Waterbody In Terms of Their Importance to the Public Considering Any Legal or Other Constraints That Exist on Water Quality Management Approaches Within the Watershed

  The Proper Prioritization of Both Near-Field and Far-Field Water Quality Impacts Within a Watershed May Require Acquisition of Additional Information That May Not Be Available

  The Prioritization Should Be Reexamined Every Few Years, i.e., Five Years to Incorporate New Information That Has Been Developed and Changes in Use of the Waters Within a Watershed

Development of Technically Valid Watershed Approach for Water Quality Management (continued)

- Assess the Current Information on the Causes of Water Quality Use Impairments Within the Waterbody

  If There is Aquatic Life Toxicity, What Constituent(s) is Responsible For It?

    Do Not Assume That Exceedance of Water Quality Criteria - Standards For Potentially Toxic Chemicals Represents a Real Water Quality Use Impairment - Use Toxicity Tests and TIEs

- Through Forensic Analysis, Determine the Specific Sources of the Pollutants That Cause Water Quality Use Impairments Within the Watershed That Are of Sufficient Magnitude to Require Control

- Develop and Implement Site-Specific Control Programs For Each of the Sources of Pollutants That Significantly Impairs the Near-Field or Far-Field Uses of the Waterbody

  Focus Control Programs on Sources Rather Than Trying to Treat Stormwater Runoff From Urban Areas, Highways and Rural Areas

Development of Technically Valid Watershed Approach for Water Quality Management (continued)

- Implement Pollution Prevention Program Designed to Detect Potentially Emerging Problems

  Focus Pollution Prevention on Control of Pollutants Not Chemical Constituents Irrespective of Whether They Are Potentially Adverse to Water Quality

- Repeat the Evaluation Monitoring Approach for Each Potentially Significant Water Quality Problem Every Five Years

Overall, Approach Is Technically Valid and Cost-Effective

  Utilizes Current Understanding of Factors Influencing the Water Quality Significance of Chemical Constituents in Aquatic Systems

Overall Approach to Implementation of Evaluation Monitoring

- Work with Dischargers, Regulatory Agencies and Others in Defining Existing and Potential Water Quality Problems of the Receiving Waters for ETC Runoff, Prioritize the Significance of these Problems, Define How the Available Funds Will Be Used to Address these Problems
  - Define Real Water Quality Use Impairment(s)
  - Determine Cause of Water Quality Problems
  - Determine Source of Constituents that Cause Problems
  - Work with Regulatory Agencies and Others in Development of BMP's to Control Input of Constituents Responsible for the Water Quality Impacts to the Maximum Extent Practicable
  - Cycle Through the Potential Impacts Every Five-Year NPDES Permit Period

Supplemental Information

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Summary Biographical Information

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Dr. G. Fred Lee holds a PhD degree from Harvard University in Environmental Engineering and Environmental Sciences and a Master of Science in Public Health degree from the University of North Carolina. He obtained a bachelors degree from San Jose State University.

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Dr. G. Fred Lee has conducted over $5 million in research on various aspects of water quality and solid and hazardous waste management. He has published over 650 papers and reports on this work. He has served as an advisor to numerous governmental agencies and industries in the US and other countries on water quality and solid and hazardous waste management issues.

Dr. G. Fred Lee and Dr. Anne Jones-Lee have extensive experience in developing approaches that work toward protection of water quality without significant unnecessary expenditures for chemical constituent control. They have been active in developing technically-valid, cost-effective approaches for the evaluation and management of chemical constituents in domestic and industrial wastewater discharges, contaminated sediments, and urban area, highway and rural stormwater runoff since the 1960s.

Throughout Dr. Lee's career he has been involved in developing the watershed management approach for water quality evaluation and management. He pioneered in developing this approach for managing excessive fertilization of lakes, reservoirs and near-shore marine waters. He and Dr. Jones-Lee have recently been active in developing the evaluation monitoring approach for defining the water quality problems associated with point and non-point source discharges and runoff.

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Development of Technically Valid Watershed Approach for Water Quality Management (continued)

- The Stakeholders - the Public Should Prioritize the Water Quality Use Impairments Within the Waterbody In Terms of Their Importance to the Public Considering Any Legal or Other Constraints That Exist on Water Quality Management Approaches Within the Watershed

  The Proper Prioritization of Both Near-Field and Far-Field Water Quality Impacts Within a Watershed May Require Acquisition of Additional Information That May Not Be Available

  The Prioritization Should Be Reexamined Every Few Years, i.e., Five Years to Incorporate New Information That Has Been Developed and Changes in Use of the Waters Within a Watershed

Development of Technically Valid Watershed Approach for Water Quality Management (continued)

- Assess the Current Information on the Causes of Water Quality Use Impairments Within the Waterbody

  If There is Aquatic Life Toxicity, What Constituent(s) is Responsible For It?

    Do Not Assume That Exceedance of Water Quality Criteria - Standards For Potentially Toxic Chemicals Represents a Real Water Quality Use Impairment - Use Toxicity Tests and TIEs

- Through Forensic Analysis, Determine the Specific Sources of the Pollutants That Cause Water Quality Use Impairments Within the Watershed That Are of Sufficient Magnitude to Require Control

- Develop and Implement Site-Specific Control Programs For Each of the Sources of Pollutants That Significantly Impairs the Near-Field or Far-Field Uses of the Waterbody

  Focus Control Programs on Sources Rather Than Trying to Treat Stormwater Runoff From Urban Areas, Highways and Rural Areas

Development of Technically Valid Watershed Approach for Water Quality Management (continued)

- Implement Pollution Prevention Program Designed to Detect Potentially Emerging Problems

  Focus Pollution Prevention on Control of Pollutants Not Chemical Constituents Irrespective of Whether They Are Potentially Adverse to Water Quality

- Repeat the Evaluation Monitoring Approach for Each Potentially Significant Water Quality Problem Every Five Years

Overall, Approach Is Technically Valid and Cost-Effective

  Utilizes Current Understanding of Factors Influencing the Water Quality Significance of Chemical Constituents in Aquatic Systems

Overall Approach to Implementation of Evaluation Monitoring

- Work with Dischargers, Regulatory Agencies and Others in Defining Existing and Potential Water Quality Problems of the Receiving Waters for ETC Runoff, Prioritize the Significance of these Problems, Define How the Available Funds Will Be Used to Address these Problems
  - Define Real Water Quality Use Impairment(s)
  - Determine Cause of Water Quality Problems
  - Determine Source of Constituents that Cause Problems
  - Work with Regulatory Agencies and Others in Development of BMP's to Control Input of Constituents Responsible for the Water Quality Impacts to the Maximum Extent Practicable
  - Cycle Through the Potential Impacts Every Five-Year NPDES Permit Period

Regulating Drinking Water Quality at the Source

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Abstract

The increasingly stringent requirements being placed on domestic water supply finished water quality are causing water utilities and regulatory agencies to give greater consideration to the possibility of managing water supply contaminants at the source. This paper reviews several aspects of the information available on the potential for controlling domestic water supply water quality by source pollutant control. Consideration is given to both surface and groundwater systems. Emphasis is given to the control of raw water quality problems due to excessive growths of algae, trihalomethane precursor sources, and the protection of groundwater quality from landfill leachate. Particular attention is given to the Sacramento-San Joaquin River Delta system which serves as a domestic water supply for approximately 20 million people in California.

Increasing concern is being focused on the use of copper sulfate as an algicide in water supply reservoirs because of the finding that some cities have "excessive" amounts of copper in their wastewater discharges from this source. The "excessive" concentration is based on a comparison with US EPA water quality criteria. It is well known that copper exists in many forms, only some of which are toxic. It has been found that in a number of situations the copper in surface waters is in a nontoxic form. The US EPA criteria however consider all forms of copper to be equally toxic. It is therefore important for water utilities that utilize copper for algae control to work with state regulatory agencies to be certain that the copper water quality standards adopted for the municipalities' wastewater discharges properly focus on the control of copper that leads to toxic forms in the receiving waters.

It has been found that several water utilities and agencies that use Delta waters as a raw water source are experiencing significant algal related water quality problems, including tastes and odors, and increases in trihalomethane precursors. The preliminary calculations show that it may be possible to significantly reduce the growth of algae in the Delta and in down-Delta water supply reservoirs as well as the aqueduct system transporting waters from the Delta to the southern part of the state through limiting phosphorus input to the Delta by treating domestic wastewaters for phosphorus control.

A discussion is presented on the impacts of eutrophication of Lake Tahoe on the use of this waterbody as a source of domestic water supply and on the approach that should be considered to manage the excessive algal growths that are occurring within this waterbody that lead to water supply taste and odor problems. The growth of algae in Lake Tahoe is limited by the nitrogen loads to the lake. These loads have been increasing over the years. Nitrogen is primarily derived from atmospheric sources through precipitation to the lake's surface. The primary source of atmospheric nitrogen in the Lake Tahoe basin is automobile, bus, and truck engine exhaust discharge of NOx. It is also concluded that the fertilization of lawns and other shrubbery, including golf courses, within the Lake Tahoe basin is leading to significant growths of attached algae in the nearshore waters of the lake. The fertilizers are transported via groundwater to the nearshore waters of the lake. It appears that these growths may be contributing to the

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D-044195

domestic water supply water quality problems that water utilities using Lake Tahoe water as a source have been experiencing in the past few years. In order to protect domestic water supply water quality it is recommended that water utilities that utilize Lake Tahoe as a raw water source work aggressively toward limiting automobile and other internal combustion engine vehicular traffic in the Lake Tahoe basin. Further, water utilities should also aggressively pursue banning all lawns and lawn and shrubbery fertilization within the Lake Tahoe basin.

It has been found that the current implementation of regulations governing land disposal of wastes in municipal landfills is not adequate to protect groundwater quality in California. The current approach of using plastic and compacted clay liners for landfills postpones the water pollution problems; it will not prevent them. A guide is provided to municipal water utilities and agencies on the approach that they should adopt to provide for far greater groundwater quality protection from landfill leachate and other sources of pollutants than is being achieved today.

Introduction

Municipal water utilities are facing ever increasing demands to improve finished water quality. This situation is causing many water utilities to initiate new treatment processes or approaches as well as to improve the performance of existing treatment works. These various improvements are adding to the cost of producing a potable and palatable domestic water supply. Many water utilities are finding that increased urbanization and industrialization of their water supply watersheds is causing increased contaminant loads that must be removed in the treatment works. Both of the above mentioned factors are causing water utilities and water quality regulatory agencies to consider the feasibility of controlling domestic water supply water quality by controlling contaminant concentrations at the water supply source. This paper presents an overview of the current information on some programs that have been, or could potentially be, successful in improving domestic water supply raw water quality.

Eutrophication of Domestic Water Supply Lakes and Reservoirs

The eutrophication (excessive fertilization) of domestic water supply lakes and reservoirs is a well known cause of water supply water quality deterioration. The growth of planktonic algae in domestic water supplies is known to cause increased tastes and odors, shortened filter runs, increased chlorine demand, increased turbidity, and, for some situations, increased trihalomethane (THM) precursors. Gilbert (1991) reported that surveys taken of consumer satisfaction with a domestic water supply aesthetic quality found that for the East Bay Municipal Water District, about 70 percent of the respondents indicated that they found that their water supply aesthetic quality was satisfactory. For the San Francisco Bay region as a whole, consumer satisfaction was about 35 percent. For the state as a whole, it was about 25 percent. Since taste and odor problems are one of the primary causes of consumer dissatisfaction with water supply water quality and since in California water supply taste and odor problems tend to be of algal origin, it is clear that algal growth in surface water supplies in this as well as other states is a frequent cause of significant algal-related taste and odor problems. For additional information on the impact of algae on domestic water supply taste and odors and other water quality problems, consult Palmer (1959).

Controlling Algal Growth through the Use of Copper Sulfate

Many water utilities that depend on impounded surface water as a supply have for many years been practicing algae control through the use of toxic chemicals, such as copper sulfate, to kill algae. It is generally possible for water utilities through an aggressive raw water supply water quality monitoring program to detect the early stages of an algal bloom (large number) before the algae develop in sufficient numbers to cause serious raw water quality deterioration. At that time, it is possible to use copper sulfate

D-044196

to control the algal bloom before it develops to the degree that causes severe domestic water supply water quality problems. Jones and Lee (1982) provided guidance to water utilities on the type of raw water quality monitoring program involving the measurement of algal chlorophyll that water utilities should practice in order to minimize water quality problems caused by excessive growths of algae.

With the efforts of the US EPA and many state water pollution control agencies to control toxic chemicals in wastewater effluents, the use of copper sulfate as an algicide in domestic water supply reservoirs is being increasingly questioned as a result of some municipalities, such as New York City, finding that the primary source of copper in the City's wastewaters and New York Harbor is its use for algae control in its water supply reservoirs. A similar situation appears to be occurring in South San Francisco Bay where "excessive" concentrations of copper are being found in Bay waters compared to US EPA water quality criteria and state of California proposed water quality objectives. It is alleged that this copper is derived at least in part from the use of copper as an algicide in water supply reservoirs for communities that discharge their wastewaters to the Bay. It is now becoming apparent that the continued use of copper sulfate for algae control will have to be much more judiciously practiced than has occurred in the past where the residual copper cannot be carried to any significant extent into the distribution system and thereby become part of the city's wastewater discharges.

An important aspect of this situation that should be considered is that in both New York Harbor and South San Francisco Bay, the "excessive" copper compared to aquatic life water quality criteria and standards is non-toxic to sensitive forms of aquatic life. Such a situation can readily lead to water utilities having to reduce the use of copper for algae control in the name of protecting aquatic life in receiving waters for the wastewater discharges, yet have little or no impact on aquatic life in the receiving waters for the copper derived from municipal water utility use. This is a result of the fact that copper exists in a variety of chemical forms, only some of which are toxic to aquatic life. Certain waterbodies, such as shallow marine bays, tend to convert copper to nontoxic forms.

The above described situation as well as other similar situations, where chemicals used in water treatment practices are becoming pollutants in receiving waters, will require that water utilities take a much more aggressive approach toward helping to develop technically valid, cost-effective water quality criteria and standards-objectives. The State Water Resources Control Board staff has proposed the use of US EPA water quality criteria as a basis for state water quality objectives. As discussed by Lee and Jones (1990), such criteria are based on worst case or nearly worst case assumptions and therefore in most situations are overly protective of aquatic life compared to what could be achieved if more appropriate criteria and objectives were utilized.

Because of the concern about the toxicity of copper to aquatic life in lakes and reservoirs used for recreational purposes and/or the cost of treating some lakes and reservoirs with copper sulfate, many water utilities could not or do not practice algal control through controlling algal blooms with copper sulfate. While typical eutrophication control programs based on reduction of algal nutrient input to a lake or reservoir that have been adopted across the US focused primarily on managing the impacts of algae on recreational use of the waters where the algal related problems were floating scum, decaying algae on the beach, malodorous conditions, low light penetration, dissolved oxygen depletion in hypolimnetic (bottom) waters, fish kills, etc., one of the benefits of such programs has been improvement in the domestic water supply raw water quality. With increasing constraints on water utilities' use of copper sulfate, water utilities should give greater consideration to controlling algal growth in their lake or reservoir water supply by limiting algal nutrients added to the waterbody from its watershed.

In the early 1980's, Lee and Jones, working through the American Water Works Association Quality Control in Reservoirs Committee, attempted to have the manager of the US EPA's "Clean Lakes Program" include within the scope of this program the protection and improvement of domestic water supply raw water quality. The manager of the program at that time in Washington, DC indicated that this was inappropriate. Subsequently, however, under new management, the program apparently considers the benefits of improving domestic water supply raw water quality as part of the justification for lake remediation programs supported by the agency. This situation may provide the opportunity for water utilities to gain some funding from federal and state sources for nutrient control programs.

Lee and Jones (1988a) presented a comprehensive review on the North American experience in eutrophication control through phosphorus management. As they discussed, with few exceptions, it has generally been found throughout the world that controlling the phosphorus input to a freshwater lake or reservoir can, if practiced to a sufficient extent, reduce the amount of algae that would develop in the waterbody. Since typically algal related domestic water supply water quality problems are related to the numbers of algae present, reducing algal biomass in a water supply reservoir is in the direction of reducing domestic water supply raw water quality problems due to algae. There are, however, significant differences in the ability of various types of algae to cause domestic water supply water quality problems. Certain types of algae are well known for their highly obnoxious, very potent odors associated with their presence in a water; this is especially true for certain blue-green algae which are known to have odors that are characterized as "pig-pen" like. Normally, however, it is found that reducing the overall nutrient (phosphorus) loads to a lake or reservoir tends to be in the direction of not only reducing total algal biomass, but also reducing the frequency and severity of highly obnoxious algal blooms. For further discussion of this topic, consult Lee (1973).

Lake Tahoe Water Quality

The use of Lake Tahoe as a domestic water supply source provides an unusual example of the potential involvement of water utilities in managing eutrophication of a lake or reservoir through limiting nutrient inputs to the waterbody. Recently the authors have completed a review of the available information on the factors controlling algal related water quality in Lake Tahoe (Jones and Lee, 1990). The majority of this data was developed by Dr. Goldman and his associates at the University of California at Davis and the Lake Tahoe Research Group. It was found that both the phytoplankton (open water suspended algae) and the periphyton (nearshore attached algae) have been increasing in numbers with a concomitant adverse impact on the lake's water quality. Based on decreased Secchi depth (water clarity) and primary productivity, the numbers of planktonic algae have been increasing significantly in the open waters of the lake. (See Figures 1 and 2.) Similarly, although not as well documented, increased growth of periphyton is occurring in nearshore waters.

Lee, et al., (1978) and Rast and Lee (1978) developed a relationship between planktonic algal chlorophyll in lakes and reservoirs and Secchi depth where increased algae causes reduced light penetration. It is clear from the data of Goldman and others that while Lake Tahoe is ultra-oligotrophic and is one of the clearest lakes in the world, increased algal growth is occurring in this lake that is significantly reducing light penetration in the water column.

During the past several years some water utilities using Lake Tahoe as a raw water source have been experiencing significant problems with algal related tastes and odors. At this time it is not clear whether the problem is due to planktonic algae or attached algae that have broken off from their attachment or a combination of both. Some water utility personnel feel that this problem may have been exacerbated by the low water levels that have occurred in Lake Tahoe over the last few years. Additional work will have to be done to determine the relative role of planktonic algae, attached algae, and low water levels to sort out the specific causes of the taste and odor problems.

D-044198

Figure 1

Decrease in Lake Tahoe's Annual Average Secchi Depth

(After Goldman, 1988)

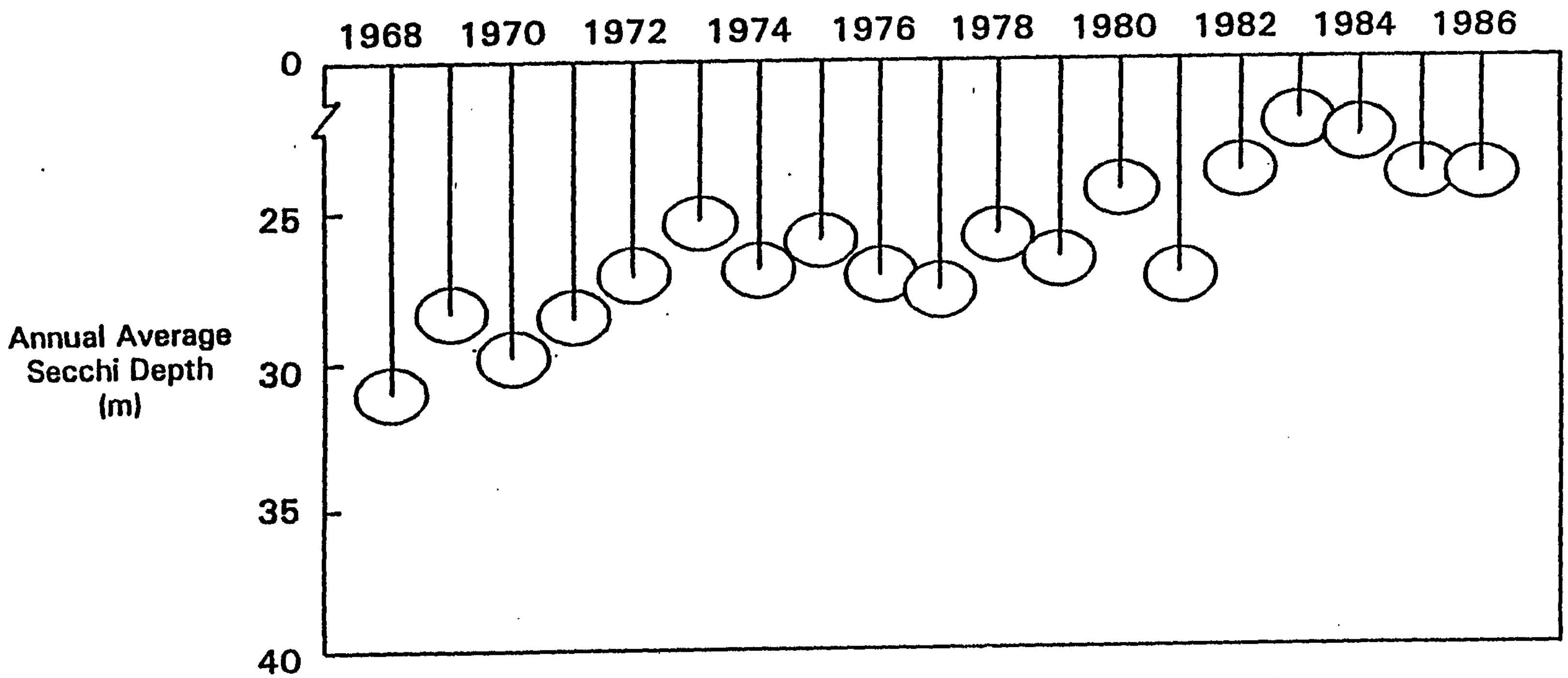

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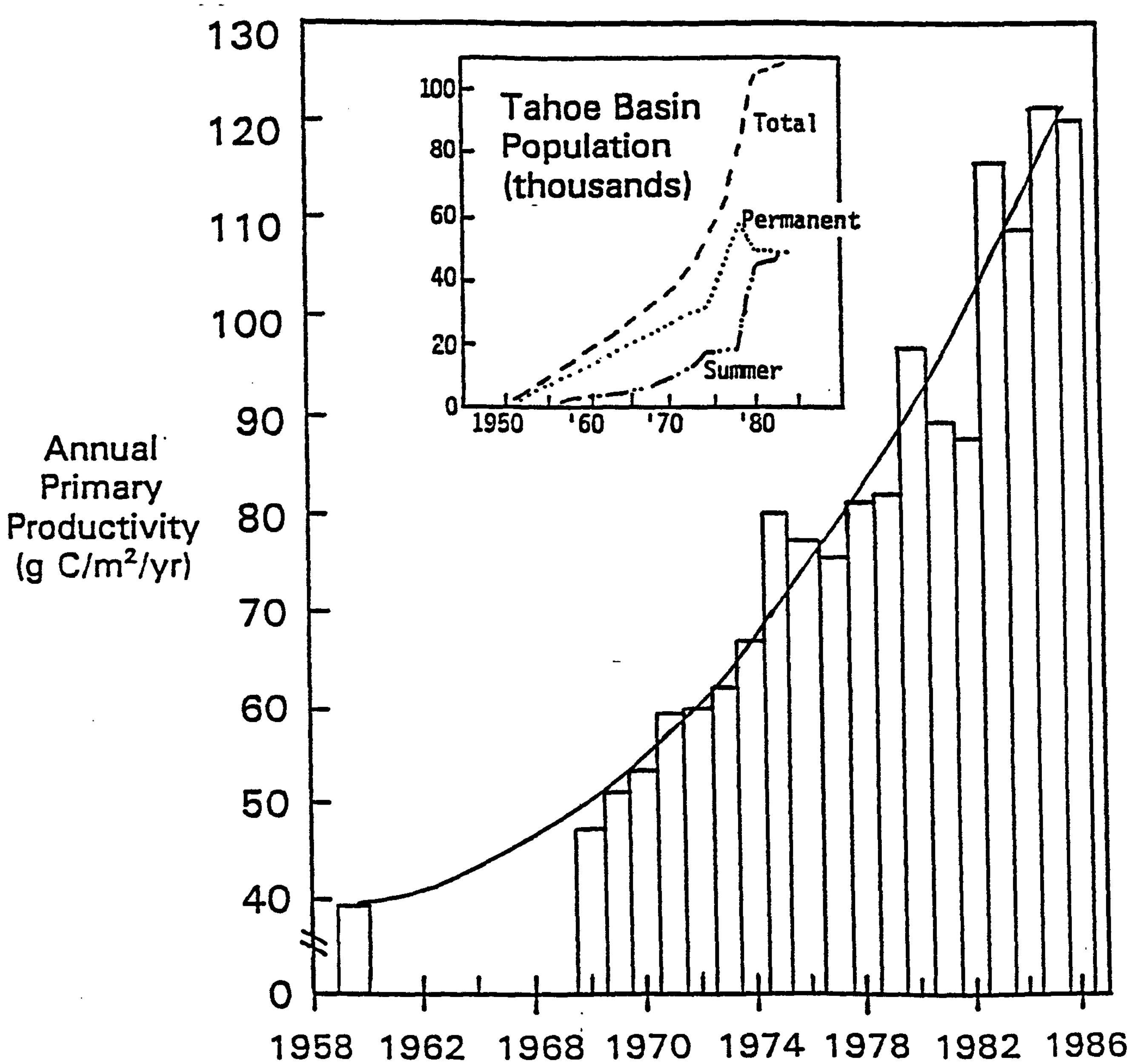
Figure 2

Increase in Lake Tahoe's Primary Productivity

(After Goldman, 1988)



In the review by Jones and Lee (1990) it was found that the growth of planktonic algae in the lake is primarily controlled by the input of nitrogen to the lake. Using the techniques described by Jones and Lee (1986) and Rast and Lee (1984) to determine sources of nutrients for the lake, Jones and Lee (1990) concluded that the primary source of nitrogen which is stimulating algal growth is from the atmosphere and that based on the NOx emissions from vehicular exhausts in the Lake Tahoe Basin, it is concluded that automobile, bus, and truck traffic within the Lake Tahoe watershed is the primary source of nitrogen that is causing the increased algal growth in the lake.

Table 1 presents estimated nitrogen loads for Lake Tahoe for about 1950 (predevelopment) conditions and today. The predevelopment nitrogen loads to Lake Tahoe are estimated to be about 7 metric tons per year while today the total nitrogen load is about 100 metric tons per year. The most significant increase has been in the atmospheric nitrogen sources with direct precipitation on the lake's surfaces being the primary source of nitrogen for the lake. According to the Air Resources Control Board (1987) data (Table 2), vehicular traffic contributes about 2,500 metric tons per year of NOx to the atmosphere. This is equivalent to about 700 metric tons of nitrogen per year. It is therefore evident that automobile, truck, and bus exhaust discharges of NOx are highly significant sources of nitrogen for Lake Tahoe.

Jones and Lee also concluded that the Lake Tahoe Regional Planning Agency's (TRPA) Individual Parcel Evaluation System (IPES), which is being used to control population growth in the basin, is technically invalid and is not protecting the lake's water quality. The IPES score is a growth limiting mechanism used by TRPA for the purpose of protecting lake water quality. The IPES score on a property is not related to the amount of nitrogen or, for that matter, other forms of algal available nutrients that ultimately reach the lake from that property. Jones and Lee recommended that in order to begin to effectively slow down the rate of deterioration of the lake water quality that is related to algal growth in the open and nearshore waters of the lake, aggressive action should be immediately taken toward greatly reducing, if not essentially eliminating, the use of internal combustion engine based automobiles, trucks, and buses within the Lake Tahoe watershed.

Jones and Lee also concluded, based on the work of others and personal observations, that part of the periphyton growing in the lake is due to nutrients derived from fertilizers used on lawns and shrubbery, including golf courses, etc. A significant part of the fertilizers used for landscaping purposes by public and private interests is being carried by groundwater to the nearshore waters of the lake where it stimulates periphyton growth in the region where the groundwaters enter the lake as submerged springs. Jones and Lee recommended that all lawns, including golf courses, and fertilized shrubbery be banned in the Lake Tahoe watershed. The basin should be allowed to return to native vegetation that does not require fertilization and/or irrigation.

While at this time domestic wastewater disposal is not allowed within the Lake Tahoe watershed, i.e., the system is sewered with the wastewaters exported out of the watershed, it is highly likely that previous wastewater disposal practices could be significant sources of nutrients for some nearshore areas of Lake Tahoe contributing to localized algal related problems in these areas. Nutrients derived from the previous use of septic tank wastewater disposal systems and wastewater spray irrigation disposal systems are, or could be, significant sources of nutrients which stimulate algal growth in some parts of the nearshore waters of Lake Tahoe. Jones and Lee suggested that additional work needs to be done to determine the potential significance of past wastewater disposal practices within the Lake Tahoe Basin as a source of nutrients for nearshore water quality problems. If there is interest in controlling excessive periphyton growth in a particular part of the nearshore area of the lake where the nutrients contributing to the excessive growth in that region are significantly derived from past wastewater disposal practices, it may become necessary to intercept the groundwater before it reaches the lake by pumping and treating the groundwater to remove the nutrients.

Table 1

Lake Tahoe
Estimated N Load
(tonnes N/yr)

After Jones and Lee, (1990)

Source	*Pre-Development*	*Now*
Atmosphere - onto Lake Surface	2.5	~100
Surface Water Runoff	4	16
Groundwater	0.5	2
Total N Loads	7	118

D-044202

Table 2

Estimated Contributions of NOX from Motor Vehicles

After Jones and Lee, (1990)

	tonne NOX/yr
Automobiles	800
Light & Medium Trucks	630
Heavy Duty Trucks	1160
	= = =
Total	2500

Source: Air Resources Control Board, 1987

If the algal tastes and odors continue to persist, the water utilities using Lake Tahoe as a source should become proponents of significantly curtailing internal combustion engine based vehicular traffic within the Lake Tahoe Basin and eliminating the use of lawn and shrubbery fertilizers and irrigation within the basin as part of a domestic water supply source water quality control program. There can be little doubt that, if aggressive action is not taken in the near future in these areas, the frequency and severity of algal caused tastes and odors and other domestic water supply water quality problems will increase.

Impact of Water Supply Intake Location on Water Quality

Lee and Harlin (1965) discussed the benefits that water utilities could potentially develop in improved raw water quality by having lake or reservoir intake works designed so that water can be taken from various specified depths at certain times during the year. For more eutrophic waterbodies, it is often found that algal blooms tend to occur near the surface, where the numbers of algae and their potential impact on raw water quality decrease significantly with depth. This is especially true during the summer months when the waterbody may be thermally stratified. It therefore is possible that a water utility that has the option of taking water at various depths in a lake or reservoir (see Figure 3) could significantly improve the raw water quality that is influenced by algae by selecting water intake depth to minimize algal-related problems, such as tastes and odors, shortened filter runs, THM precursors, and anoxic waters with the associated elevated concentrations of iron, manganese, and sulfide. For such a program to be successful, however, the water utility will need to conduct a fairly intensive reservoir monitoring program to gain an understanding of how raw water quality changes with depth at various times of the year and under various meteorological conditions. Further information is provided on this topic by Lee and Harlin (1965).

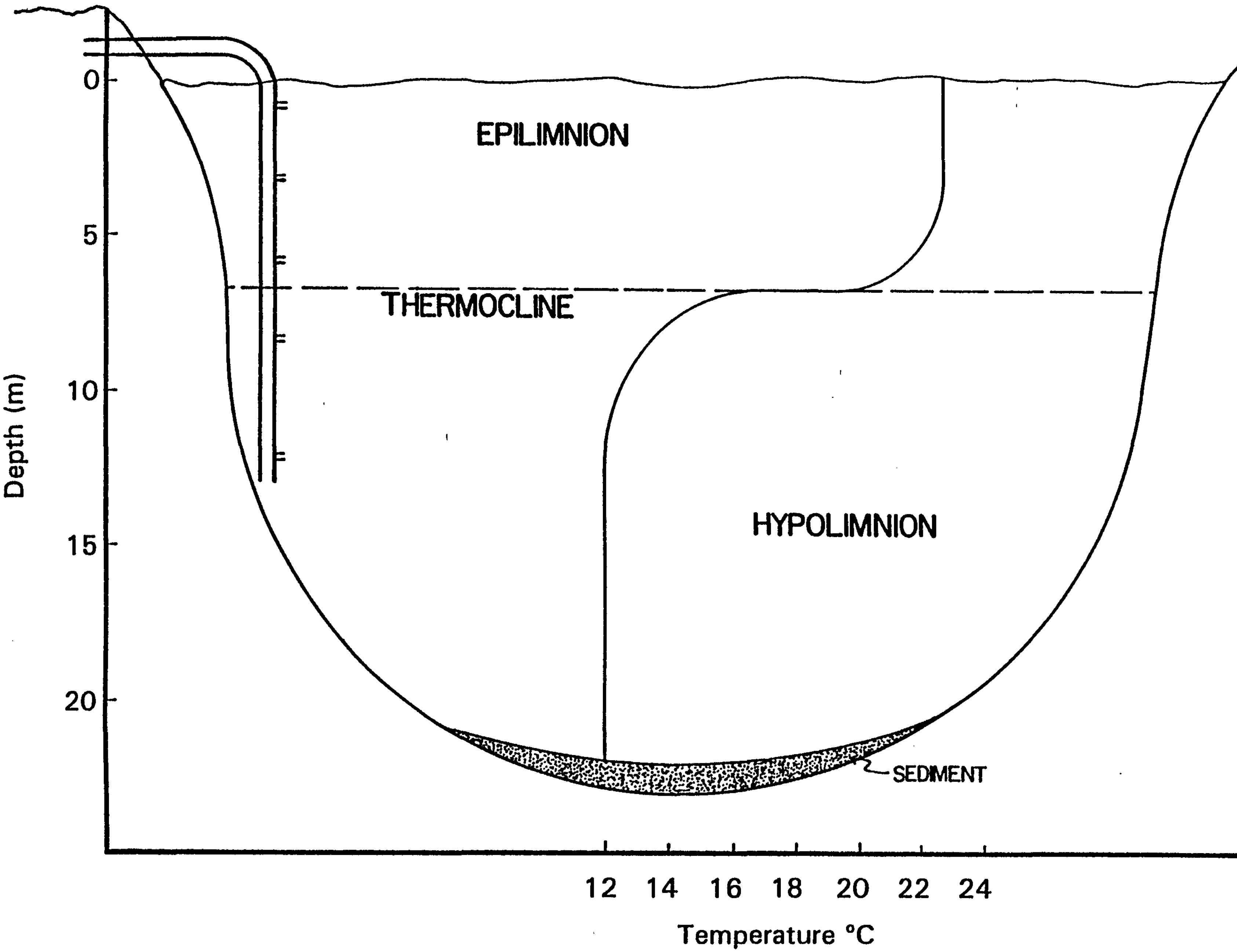
Eutrophication of Rivers Used as Domestic Water Supplies

While the eutrophication of lakes and reservoirs' impact on domestic water supply water quality and its potential control by limiting phosphorus input to the waterbody are well known, the eutrophication of rivers and its effects on domestic water supply water quality are not well understood. There is no question, however, about the fact that algal growth in rivers can cause severe water quality problems for domestic water supplies. Rivers frequently carry relatively large numbers of algae. The difference between rivers and lakes and reservoirs however is that the algae present in a lake or reservoir are more readily discernible to the public because of the more quiescent conditions that typically exist in lakes and reservoirs compared to the turbulent conditions that frequently occur in rivers. Further, many rivers tend to be highly turbid due to inorganic turbidity derived from the transport of erosional materials. Such turbidity masks the presence of algae and may under severe conditions limit their growth due to reduced light penetration.

In some unpublished work by the senior author conducted on the upper Ohio River in 1960-61, it was found that the passage of elevated concentrations of algae in the river by a water supply intake caused the water utility to experience increased tastes and odors, shortened filter runs, etc. Slugs of algae that were present in the Ohio River arose from growth in the river as well as growth in reservoirs that served as the source of water for the river. If water utilities would monitor the planktonic algal chlorophyll in their river water supply and correlate this with algal related water quality problems, in many instances, they would find sufficient correlation to cause considerable justification for controlling nutrient inputs to rivers from upstream sources. There also may be sufficient justification in some situations to cause the managers of head water reservoir systems to be cognizant of the fact that, if they release surface water from a reservoir that has a high concentration of algae, this water may cause significant water quality problems for down river utilities. It should be possible in many multiple reservoir management situations to include consideration of domestic water supply water quality as it relates to algal growth in the reservoirs and the release of reservoir water to the river in developing reservoir release programs.

Figure 3

Selective Withdrawal from Water Supply Reservoir



THM Precursor Sources and Their Control

One of the most significant water quality problems for domestic water supply utilities that utilize surface waters as a source is the formation of THM's in the waters disinfected by chlorine or other strong oxidants, such as ozone in the presence of bromide. THM's arise from chlorine (primarily free chlorine) reacting with dissolved and particulate organic matter present in the raw water to form a group of low molecular weight halogenated hydrocarbons, such as chloroform. In the presence of bromide in the raw water, strong oxidants, such as free chlorine and ozone, oxidize the bromide to bromine. The bromine in turn reacts in a similar manner to free chlorine, forming brominated THM's.

The presence of bromide in a water supply is of particular significance as a THM precursor because it is much heavier than chlorine and therefore, since the THM MCL (maximum contaminant level) is based on a mass per volume concentration, a brominated THM is a much more important species than its equivalent chlorinated form with respect to meeting the MCL. It also appears that bromine may be a more effective halogenating agent than chlorine with the result that higher THM levels on a molar basis are formed when bromide is present compared to when it is absent. Bromides are frequently associated with seawater and brines. It is therefore obvious that water utilities with any sources of controllable bromide within their raw water supply should aggressively require control of those sources to the maximum extent possible.

Until recently, few water utilities determined the bromide concentration of the raw water supply with the result that there is very limited information available today on the pollution of water supplies by bromide. For seawater systems, the chloride to bromide ratio in accord with the law of constant relative proportions is a fairly well-defined ratio of about 0.003. As a result, for freshwaters contaminated with seawater, such as occurs in part of the San Joaquin-Sacramento River Delta (Delta), it is possible to estimate the bromide concentration of the water based on the chloride concentration. For other sources of bromide, however, such as an oil field or other brines, the seawater ratio may not be applicable to waters contaminated by brines from other sources. Caution should therefore be exercised in a complex system such as the Sacramento-San Joaquin River Delta system in assuming that all tributaries of the Delta have chloride to bromide ratios the same as seawater. While this could be the case, since the export of Delta water contaminated with seawater results in some of this water being returned to the Delta through the San Joaquin River system, it is important to verify, for this and other similar situations, that chloride concentrations can be used to estimate the bromide content of the water.

There is considerable justification for limiting the amount of seawater that enters the Delta in order to reduce the bromide input to this system and to reduce the potential for brominated THM formation. In the fall of 1990, the State Water Resources Control Board Delta Municipal and Industrial Water Quality Work Group made a recommendation to the California Water Resources Control Board to manage water quality within the Delta system so that the freshwater outflows from the Delta to the San Francisco Bay system will be sufficient to limit the saltwater migration into the Delta for the purpose of controlling the introduction of bromide in the seawater into Delta waters that are exported or used directly for municipal water supply sources. This is a highly justified source water quality control effort that is under review by the State Water Resources Control Board at this time.

Another example of a situation where bromide control in a source water was highly justified occurred in the work that the authors did with the Canadian River Municipal Water Authority, which utilized Lake Meredith in West Texas as a domestic water supply source (Lee and Jones, 1983). This lake received brine drainage to tributaries. This brine was derived from natural sources in the Canadian River watershed. It contained elevated concentrations of bromide which led to elevated brominated THM's in water supplies that use Lake Meredith water as a source. Efforts were made by the Canadian River Municipal Water Authority to control the amount of brine input to the tributaries of the reservoir for the purpose of limiting brine, and specifically bromide, input to the waterbody.

While it has been known for many years that controlling the concentration of organic precursors of THM's by their removal in treatment works can control THM concentrations, surprisingly little attention has been given to attempting to understand, and where possible control, organic THM precursors at the source. This is an area that deserves attention and that could be a potentially significant approach that could be utilized by some water utilities for controlling excessive THM's. The work of Randtke and his associates (Randtke, et al., 1988) has provided some insight into the potential sources of THM precursors. Table 3 presents a summary of Randtke, et al. data on the concentrations of THM precursors as measured in a standardized chlorination test (THMFP-trihalomethane formation potential) in various runoff waters and samples of effluents, etc. It is readily apparent from this and other work that certain types of land use and wastewater discharges are particularly significant sources of THM precursors. Randtke, et al. (1988) found that while THM precursor concentration in waters from various sources varied greatly, the THM yield as measured as THMFP concentration per mg carbon was remarkably constant. This points to the potential that for many situations controlling the total organic carbon (TOC) content of the water is a potentially reliable basis for controlling THM precursors. Obviously, there is need for additional study of the applicability of the Randtke, et al. results to other areas to be certain that the relatively constant ratio that they found between THM formation potential and TOC is found in other areas. There is some indication in the literature that this may not be the case. Water utilities and water pollution control agencies would therefore need to make an evaluation of this relationship of potentially significant sources of organic THM precursors in their watersheds in order to determine if the THM precursor source control program could be focused on controlling TOC discharge to waters that are tributary to the water supply source for the water utility.

While THM organic precursors are derived from natural sources, such as decaying vegetation, etc., the activities of man through municipal and industrial wastewater discharges and agricultural run-off and drainage can significantly increase the THM precursor concentrations in a water supply. If a much better understanding existed of THM precursor sources and the amounts of precursors derived from various types of land use, then it might be possible to develop approaches that could effectively reduce precursor input. An example of this type of work is currently underway in the Delta by the California Department of Water Resources (DWR) with a paper on the results of this work was presented by Woodard (1991). The DWR study focuses on Delta sources of THM precursors. It, however, does not go far enough back into the tributary sources of the Delta to understand the specific sources of THM precursors that exist in the major tributaries to the Delta upstream of the Delta. It is clear from the Department of Water Resources monitoring data (DWR, 1989) that a significant amount of THM organic precursors are brought into the Delta from tributary sources to the Delta. DWR found that the five-year (1983-87) median (THMFP's) at Greene's Landing on the Sacramento River was 260 ug/L. At Vernalis on the San Joaquin River it was 450 ug/L, while the five-year median at the bank's export point was 490 ug/L. While it would be necessary to actually compute input loads of THM organic precursors from the Sacramento and San Joaquin rivers based on concentrations and flow data, it is clear that a significant amount of THMFP's are added to the Delta each year from Delta tributary sources and that a significant effort should be made to understand the specific contributions of these various sources since it could lead to the development of control programs that could influence THM formation in water supplies that use the Delta as a water supply source. It is therefore evident that the DWR current studies in this area should be expanded to include not only the definition of in-Delta sources but also upstream of the Delta sources of THM organic precursors.

It has been known for some time from work in various parts of the US that waters in contact with high organic soils, such as peat, which occur in some parts of the Delta, can have greatly elevated concentrations of organic THM precursors. From a review of the Department of Water Resources' monitoring data on waters added to and taken off of agricultural lands within the Delta, it has been found by the authors that the waters diverted from the Delta channels to agricultural lands and then pumped back

D-044207

Table 3

THM FORMATION POTENTIAL IN RUNOFF AND POINT-SOURCE SAMPLES

Site Description	DOC mg/L	TOC mg/L	THMFP ug/L
Urban-Commercial	17.8	67.0	1,152
Industrial Landfill	257.0	337.0	1,555
Construction Landfill	6.06	19.9	967
Terraced/Tiled Farmland	4.52	203.4	4,329
Non-terraced Farmland	4.92	7.55	400
Burned Bromegrass Land	6.39	7.93	409
No-till Farmland	4.72	7.09	482
Cattle Feedlot	64.1	382.7	13,482
Tilled Farmland	16.7	29.6	1,651
Swine Feedlot	13.0	26.5	1,383
Cattle Feedlot	71.1	122.5	4,747
Soybean Field	9.92	13.6	710
Corn Field	3.74	17.2	591
Corn Field	13.4	17.3	1,008
Urban Construction	3.03	22.7	1,486
Urban Residential	5.12	6.99	395
Industrial Park	4.48	6.72	274
Shopping Center	3.09	5.22	268
Municipal Secondary Effluent (Activated Sludge)	9.15	9.57	304
Municipal Secondary Effluent (Stabilization Pond)	16.4	41.4	1,093
Municipal Secondary Effluent (Stabilization Pond)	32.7	55.3	926
Municipal Secondary Effluent (Stabilization Pond)	28.4	54.2	1,027
Sanitary Landfill Runoff Pond	3.0	3.6	154
Refinery Effluent	26.9	42.0	2,071
Cellophane Manufacturing Effluent	5.4	8.3	272
Power Plant Cooling Water	7.0	8.4	315
Power Plant Cooling Water	7.0	7.8	340
Power Plant Ash Pond Influent	3.7	3.9	151
Power Plant Ash Pond Effluent	4.7	6.1	421
Electroplating Plant Effluent	9.4	10.7	156
Meat Packing House Effluent	16.1	20.8	819
Fertilizer Plant Wastewater Pond	11.2	16.2	242

THM YIELDS OF RUNOFF SAMPLES

Sample Group	No. of Samples	Average THMFP (umoles/mgC)
All Samples	18	0.37 ± 0.14
Urban Runoff	6	0.39 ± 0.14
Agricultural Runoff	11	0.39 ± 0.11
Feedlot Runoff	3	0.35 ± 0.07
Farmland Runoff	8	0.41 ± 0.12

After Randtke et al. (1987)

to the channels will typically show a 1000 to 1500 ug/L increase in THM formation potential. It is evident from examination of the total dissolved solids (TDS) in the waters diverted from the channels to agricultural lands and the waters pumped back to the channels from these lands, that there is about a 2 to 3-fold evaporative concentration of salts on some of the agricultural lands within the Delta. This could mean that on the order of half of the increase in THM precursors discharged from Delta agricultural lands to the channels could be derived from evaporative concentration on the agricultural lands. The other half would be derived from leaching from peat soils and any crop or other plant residues present in or on the soil. It is likely that there is some change in the type of compounds that make up the organic precursors derived from the agricultural lands due to sorption, microbial transformation, and desorption-solubilization processes; and therefore, the chemical makeup of the dissolved organic carbon (DOC) added to agricultural lands will likely be different from that discharged from them. This could affect the relationship between DOC and THM formation potential since only a small part of the DOC is converted to THM's during disinfection processes involving chlorine or other strong oxidants in the presence of bromide.

It is recommended that an aggressive program be developed to reduce the amount of organic THM precursors added to Delta waters from agricultural as well as other sources. The first step in developing such a program is to better understand the relative significance of each potentially significant source for the Delta in each of its major tributaries. This program should include determination of specific sources of THM precursors that contribute more than about 10% of the total to a Delta tributary as well as within the Delta. These sources should in turn be investigated to understand what are the specific sources of THM precursors within the source and what potential control programs could be developed to reduce the amount of THM precursors present in the raw water supplies for the utilities that utilize water from the Delta. Similar kinds of programs should be conducted by water utilities throughout the country who face problems with excessive THM formation.

Ultimately, it should be possible to develop THM precursor export coefficients similar to the export coefficients that have been developed by Rast and Lee (1983) for nitrogen and phosphorus where certain types of land use or drainage would be expected to contribute certain amounts of THM precursors on a unit area per unit time basis. This would require determining the concentrations of THM precursors from various types of sources at fairly frequent intervals of one to no more than two weeks over at least a one- and preferably two-year time period while the flow of the source is also being measured. The objective of such measurements would be to develop mass THMFP per hectare per year data for runoff samples. For effluent samples, the total mass loading of THMFP's per year would be determined. This could in turn be potentially related to a population equivalent for municipal wastewaters which reflects the type and degree of treatment provided by the treatment works. For industrial wastewaters, it should be possible to develop a THMFP equivalent per unit of manufactured product or some other similar basis which relates the wastewater loads to industrial activity. It should be readily possible to determine a relationship between TOC removal in a wastewater treatment plant for certain types of wastes and a THMFP removal ratio.

The development of THM precursor export coefficients could be highly instrumental in having regulatory agencies to start to control municipal, industrial, and agricultural activities that represent significant sources of THM organic precursors for domestic water supplies. THM precursors in wastewaters, urban and agricultural drainage, etc. will ultimately be considered pollutants that have to be controlled through discharge permits in much the same way as other contaminants are being controlled today. This situation will likely arise out of the fact that while in the past it has been possible to modify disinfection practices to meet THM MCL's, in the future, this approach will not likely be possible. As a result, it will become necessary to focus THM control on significantly reducing THM precursor sources for domestic water supplies. For further information on this topic, consult Glaze (1991).

Role of Algae as THM Precursor Sources

It has been known for many years that the chlorination of laboratory algal extracts can lead to high concentrations of THM's. This has caused a number of investigators, principally Hoehn and his associates (Hoehn, et al., 1980) to investigate whether algae could be a significant source of THM precursors for domestic water supplies. Hoehn has found high concentrations of THM precursors in the presence of algal blooms in a reservoir in Virginia. Randtke, et al. (1988) conducted a series of studies specifically designed to examine the role that algae play in serving as THM precursors for the waterbodies that they investigated. They concluded that algae and other aquatic plants are not important sources of THM precursors in these waters. It appeared from their work, that while the algae and higher aquatic plants could serve as a THM precursor source, any precursors developed by or from them rapidly disappeared from the water.

It has been reported by Lee (1973) that the eutrophication of Lake Mendota located in Madison, Wisconsin that has occurred over the last 50 years or so has not changed the DOC of the lake water. At least for this waterbody, the DOC is primarily derived from terrestrial, land-based sources rather than aquatic plant, including algal, sources.

Walker (1983) has reported correlations between the phosphorus content of domestic water supply lakes and reservoirs and the THM's formed in these waters upon disinfection with chlorine. The implication is that since the phosphorus content of the lake correlates with algal chlorophyll, the algae are an important source of THM precursors. However, in the opinion of the authors, the correlation of phosphorus with THM's is spurious. It is likely that in many watersheds, phosphorus export from the land is correlated with DOC export from the land. Therefore, Walker's correlation approach cannot be judged as a valid assessment approach for determining the role that algae play as THM precursor sources.

From the information in the literature and the authors' experience, it appears now that it is important to distinguish between terrestrial and aquatic plants as THM precursor sources. While both terrestrial and aquatic plants can serve as important sources of THM precursors, it appears that the aquatic plant (algae and many macrophytes) produce THM precursors which are transitory-labile in aquatic systems. Terrestrial vegetation, on the other hand, tends to produce THM precursors, some of which are highly refractory-persistent in soils and aquatic systems. It has been suggested by Folan (1989) that this difference may be related to the lignin content of terrestrial plants. Lignin appears to be converted to highly persistent DOC. Since normally, aquatic plants have little or no lignin content, their decay, while initially producing large amounts of THM precursors, upon further microbial transformations, produce decay products which do not lead to THM formation.

While the literature on the persistence of algal-derived THM precursors is very limited, it appears to the authors that at least under warm water conditions of 15°C or greater the algal-derived THM precursors decay sufficiently in a few days to a week to non-precursor compounds. This decay would be expected to be somewhat slower in cold waters. There is obvious need to conduct in-depth studies on the formation and decay of algal-derived THM precursors in various types of aquatic systems of potential importance to water utilities. Such studies will provide utilities with the information they need to determine for their particular system whether THM precursors are derived at any time during the year to a significant extent from algal blooms in their raw water supply.

If a water utility finds, which is likely to be the case for water utilities with highly eutrophic raw water supplies, that algae represent a significant source of additional THM precursors, then there is additional justification for controlling algal populations through the use of nutrient (phosphorus and/or nitrogen) input control. Further, it may be appropriate for some utilities to develop pre-treatment of their raw water by biological means in order to bring about the decay of the algal-derived THM precursors before disinfection. This could be practiced by holding the water in the dark for a sufficient period of time to allow microbial transformation of the algal-derived THM precursors. It is likely that gentle stirring of the water such as with large paddles used in flocculation basins could accelerate the growth of bacteria which would bring about these transformations. It may be desirable to develop a modified version of a rotating biological contactor used for wastewater treatment as a means of developing sufficient bacterial populations for pre-treatment of the raw water. Such an approach would have a high probability of rapidly removing algal-derived precursors without stimulating additional algal growth or other raw water quality problems.

Water utilities that have high THM precursor concentrations in their raw water and have algal populations of greater than 10 to 20 ug/L planktonic algal chlorophyll in this raw water near the point of intake should determine if a significant part of the THM precursors are lost upon aeration and/or stirring of the water in the dark over a period of several days. If this occurs, then it may be possible to devise systems to accelerate the decomposition of labile precursors and thereby reduce the precursor load on the treatment works.

The Delta waters typically would be classified as moderately to highly eutrophic and would be expected to have a variety of algal related domestic water supply water quality problems, such as tastes and odors. It appears that the Contra Costa Water District and those whom this district supplies could expect that at least part of their THM precursor concentrations at some times in the year are derived from algae and therefore are potentially labile. This is an area that should be investigated since ultimately when the control of THM precursors from peat soils and other activities within the Delta is practiced, it could be that algae may become a very important part of the precursor sources for some of the water utilities drawing water from the Delta.

Management of Excessive Fertilization in the Delta and in Water Supply Reservoirs

A review of the State of California Department of Water Resources Delta monitoring data for the period 1983 through 1989 shows that the amount of planktonic algal chlorophyll present during the period May through July at the Clifton Court Forebay averages about 7 to 25 ug/L. Many of the values are in the 10 to 20 ug/L range with some values exceeding 50 ug/L. As discussed below, algal growth within the Delta is about what would be expected based on the aquatic plant nutrients (phosphorus) available for their growth within the system. Based on the experience of the authors in relating planktonic algal chlorophyll to domestic water supply water quality problems, it is typically found that when the planktonic algal chlorophyll exceeds around 7 to 10 ug/L that water utilities can experience significant algal related water quality problems. It is well known (see Palmer, 1959) that algal related domestic water supply problems depend on the specific types of algae present. Some algae at planktonic algal chlorophyll concentrations in the 20 or so ug/L range cause few problems other than shortening filter runs. On the other hand, some algal blooms on the order of 5 to 10 ug/L chlorophyll cause severe taste and odor problems. There are situations, such as discussed above for Lake Tahoe, where taste and odor problems are found in water supplies in which the planktonic algal chlorophyll is on the order of 1 ug/L. Situations of this type appear to be very rare, however. There is general agreement that any time the planktonic algal chlorophyll concentration is above 25 ug/L, water utilities can expect to experience significant algal related water quality problems.

Based on the authors' discussions on algal growth within the Delta system with various individuals, it has been found that there is considerable confusion about how well the Delta grows algae compared to what it should be doing based on its nutrient loads and characteristics. It has been found by the authors that the amount of planktonic algal chlorophyll, as measured by the DWR Water Quality Surveillance Program from 1983 to 1989, at the Clifton Court sampling station for the period May through July is in reasonably good agreement with the amount of planktonic algal chlorophyll that would be expected at this location based on the phosphorus content of the water at that location. The predicted planktonic algal chlorophyll is on the order of 10 to 15 ug/L. The measured average values vary from 7 to 25 ug/L. The predicted values are based on predictions by the use of the Vollenweider-OECD modeling relationship discussed by Jones and Lee (1986). As discussed below, the Delta appears to have about a 30-day hydraulic residence time during the summer months, and therefore, there is ample time for algae to develop to the extent allowable based on the nutrients available.

It is clear from review of the DWR data that nitrogen is not the limiting element controlling algal growth in the Delta. There are significantly surplus amounts of nitrogen compared to what is needed to support the amount of algal growth that is occurring. Further, from the work of the authors (Jones and Lee, 1986) it is clear that light is not a significant limiting factor in controlling algal growth within the Delta over the control that light limitation has in controlling algal growth in other waterbodies, i.e., the color of Delta waters is not sufficient to significantly affect the biomass of algae that develops in these waters based on their nutrient content.

It is clear from these results that the Delta is growing algae in about the same way as waterbodies located throughout the world grow algae relative to their phosphorus loads. This is not unexpected since the stoichiometry (chemical composition) of algae is the same worldwide. The fact that some parts of California have a more arid climate does not, as is sometimes asserted, cause algae in this area to be different from algae in other areas of the world. It is also clear that water utilities that use Delta water as a raw water source can expect to have algal related water quality problems in their raw water supplies. It would be expected that water utilities using Delta waters would experience significant taste and odor problems and that there would be a potential for algal derived THM organic precursors in the water.

In addition to being concerned about algal derived tastes and odors and THM precursors for those utilities who take water directly from the Delta and treat it shortly after extraction, concern should also be focused on the development of algae in reservoirs that are used to store exported Delta water before its use as a domestic water supply source. Under these conditions, it is possible that severe algal related raw water quality problems could occur as a result of algae developing in the reservoir before the water is used for domestic purposes. Some water utilities, such as the Santa Clara Water District, have reported severe algal related water quality problems in waters derived from reservoirs that were filled with Delta water. This district has found a good correlation between planktonic algal chlorophyll and taste and odor problems in their raw water source. According to Means (1991), several of the Metropolitan Water District reservoirs, such as Perris Reservoir, have experienced significant algal related taste and odor problems. Other reservoirs in the Metropolitan Water District of Southern California (MWD) system have, on occasion, experienced similar problems.

Recently Karimi and Singer (1991) have reported that Silver Lake Reservoir, which is part of the Los Angeles Department of Water and Power (DWP) municipal water supply system, has significantly increased algal derived THM's. This situation arises from the chlorination of the reservoir water within the reservoir for the purposes of controlling algal growth. According to Heyer (1991), the restrictions on the use of Mono Lake tributary water as a water supply source for DWP has resulted in having to use water supplied by the MWD as a source. While the Mono Lake tributary water had low algal nutrients, the MWD water is derived from the Delta and has a high algal nutrient content. According to Heyer, coincident with the switch from Mono Lake tributary water to Delta water was an increase in the algal related water quality problems in some of the DWP reservoirs. Since the algae that are developing in some of these reservoirs, such as Silver Lake Reservoir, are not controllable by the addition of copper sulfate, this has caused DWP to initiate chlorination of the whole reservoir for the purpose of attempting to control algal growth. Karimi and Singer (1991) have found a correlation between the THM's in this reservoir water and the algae present in the water.

The Silver Lake Reservoir system is unusual because of the whole reservoir chlorination practice. Under these conditions, the THM precursors, which are algal excretory and degradation products and the algae themselves, are converted in the lake to THM's. It therefore becomes an issue of how fast the THM's present in the lake water dissipate rather than the dissipation of algal derived THM precursors discussed above.

The algal related water quality problems, including increased algal derived THM's, associated with the use of Delta water as a raw water source raises the question of whether it would be possible to control algal growth in the Delta as well as in off-Delta reservoirs filled all or in part with Delta water through the use of nutrient control at their sources for and within the Delta.

As discussed by Lee and Jones (1988a), there are approximately 50 million people in the world whose domestic wastewaters are being treated for phosphorus removal for control of algal related water quality problems in lakes and reservoirs. This is a well established technology typically involving the addition of alum (aluminum sulfate) as part of wastewater treatment to remove phosphorus by its incorporation into the alum floc. It is also possible to remove phosphorus through the use of biological uptake, precipitation with iron salts, or with lime. All of these methods are effective and widely practiced.

Ordinarily, for treatment works treating over one million gallons per day, the total cost of 90-95% phosphorus removal from domestic wastewaters is on the order of four cents per person per day contributing wastewater to the treatment plant. It is therefore appropriate to investigate whether phosphorus present in Delta waters used by water utilities as a raw water source is derived from readily controllable sources such as domestic wastewaters discharged to Delta tributaries or within the Delta.

In order to estimate whether phosphorus removed from domestic wastewater treatment plants which contribute phosphorus to the Delta via tributaries or directly, it is necessary to estimate the total phosphorus load that stimulates algal growth in the exported water. Since in normal precipitation years the high winter-spring precipitation runoff and snow melt flows from the Sacramento and San Joaquin rivers flush the Delta and since the algal related water quality problems associated with the use of Delta water are typically summer problems, the potential benefits for removing phosphorus from domestic wastewaters contributed to tributaries of the Delta should be evaluated for the summer.

It is estimated, based on DWR data from various sources, that the average residence time of water in the Delta during the summer months is about 30 days. This is based on an estimated volume of water in the Delta of 1×10^9 m^3 and an estimated summer inflow of 15,000 cfs. It is, therefore, evident that during the summer there is ample time for algae to develop in the Delta to the extent possible from the nutrients (nitrogen and phosphorus) present in the river inflows to the Delta. Normally during summer months, about two weeks is necessary for algae to use all the nutrients they wish to use to develop peak biomass based on the characteristics of the waterbody.

It is possible that phosphorus added to the tributaries of the Delta during the fall, winter, and early spring could become important in causing algal related water quality problems during the following summer in a large reservoir that is filled with Delta waters principally derived from the Delta during the fall, winter, and spring. Under these conditions, consideration should be given to year round phosphorus removal from wastewaters and other sources should such removal be shown to have a potential benefit in reducing algal related water quality problems for utilities using waters from that reservoir.

Since 1983, the California Department of Water Resources (DWR) has been conducting an extensive monitoring program of Delta waters and its major tributaries (i.e. DWR, 1986 and other years). This monitoring program has included measurements of various nutrient species and planktonic algal chlorophyll. Based on review of this data, it is found that typically the concentrations of total phosphorus in the waters at the Clifton Court Forebay, where the waters are principally exported from the Delta, is on the order of 0.1 to 0.15 mg P/L. The typical tributary flow to the Delta during the summer months, according to various DWR documents, is on the order of 15,000 cfs. Using this flow and phosphorus concentrations, it is found that a total phosphorus load during the summer months of about 5×10^3 kg

D-044213

P/day is needed to account for the phosphorus present at the Clifton Court Forebay.

This approach assumes that all waters exported or discharged from the Delta are of the same composition as the waters at the Clifton Court Forebay. A review of the DWR data shows that the phosphorus content of the Sacramento River water near Point Sacramento and at Emmaton, both of which are just above where the main channel of the Sacramento River starts to mix with seawater, shows that the total phosphorus content of the water at this point is very similar to the phosphorus content at the Clifton Court Forebay during the summer months. Therefore, the assumption that all exported or discharged water from the Delta has a composition similar to the Clifton Court Forebay waters is reasonable.

Another approach to estimate the P load to the Delta is to determine the loads at Greene's Landing on the Sacramento River and Vernalis on the San Joaquin River. Using DWR phosphorus data for the summer at these locations and typical summer flows for these rivers, it is found that the estimated phosphorus load to the Delta is about 6 x 10^3 kg P/day. Therefore, the Clifton Court P load data and the Sacramento and San Joaquin River P load data at Greene's Landing and Vernalis, respectively, are in good agreement. It therefore appears that, at least over the summer period, the processes that take place in the Delta that remove or add phosphorus to the water tend to balance out where the phosphorus load input into the Delta is approximately equal to the phosphorus load exported and discharged from the Delta.

According to Rast and Lee (1983), the typical phosphorus per capita contribution to domestic wastewaters in the US is about 1 kg P/year. According to DWR Bulletin 160 in 1987, the Sacramento River basin had about 1.87 million people and the San Joaquin River basin had about 1.18 million people. Therefore, in these two river basins there are about 3 million people that could be contributing phosphorus to domestic wastewaters that ultimately enter tributaries of the Delta. In addition, there are about 1.3 million people in the Tulare Lake basin. However, in many years, the Tulare Lake basin does not contribute water to the Delta system. For the purposes of this review, it is assumed that the 1.3 million people in the Tulare Lake basin do not contribute phosphorus to the Delta during the summer months. It will also be assumed that between 2.5 to 3 million people in the Sacramento and San Joaquin River watersheds contribute phosphorus to the rivers or to tributaries of these rivers and ultimately into the Delta. Based on this approach about 7 x 10^3 kg P/day could be contributed to the Delta from domestic wastewater sources. According to Archibald (1991), the average estimated domestic wastewater flows to tributaries of the Delta is about 260 mgd (million gallons per day). Using 2.5 x 10^6 people as an estimate of the population contributing wastewaters to the Delta tributaries and an estimated per capita flow of about 100 gpd (gallons per day), it is found that there is good agreement between the estimated domestic wastewater flow and the average measured domestic wastewater flow.

The drainage basin for the Delta is shown in Figure 4. According to WRCB (1990), the Sacramento River drains 16,960,000 acres, the Central Sierra area drains 2,432,000 acres, and the San Joaquin River drains 7,040,000 acres. Therefore, there are approximately 26 million acres that can contribute phosphorus to the Delta from land runoff above the Delta. As reported by Rast and Lee (1984) (see Table 4), typically forested and agricultural lands contribute from 0.005 to 0.05 g P/m^2/yr. If it is assumed that the export of phosphorus from land in the Delta drainage basin is 0.01 g P/m^2/yr, it is estimated that about 3 x 10^2 kg P/day could be contributed by land runoff to the Delta tributaries. This approach assumes that the amount of phosphorus contributed from land runoff is equally partitioned for each day over the year. It is well known that this is not the case. Phosphorus contributed from land runoff typically occurs during the high runoff period in the late winter, early spring. It would be expected that except for some agricultural drainage that most of the lands in the tributaries of the Delta would contribute very little phosphorus to

Figure 4

Boundaries of the Sacramento River (5A), Central Sierra and Delta (5B), and San Joaquin (5C) Basins

After State Water Resources Control Board, (1990)

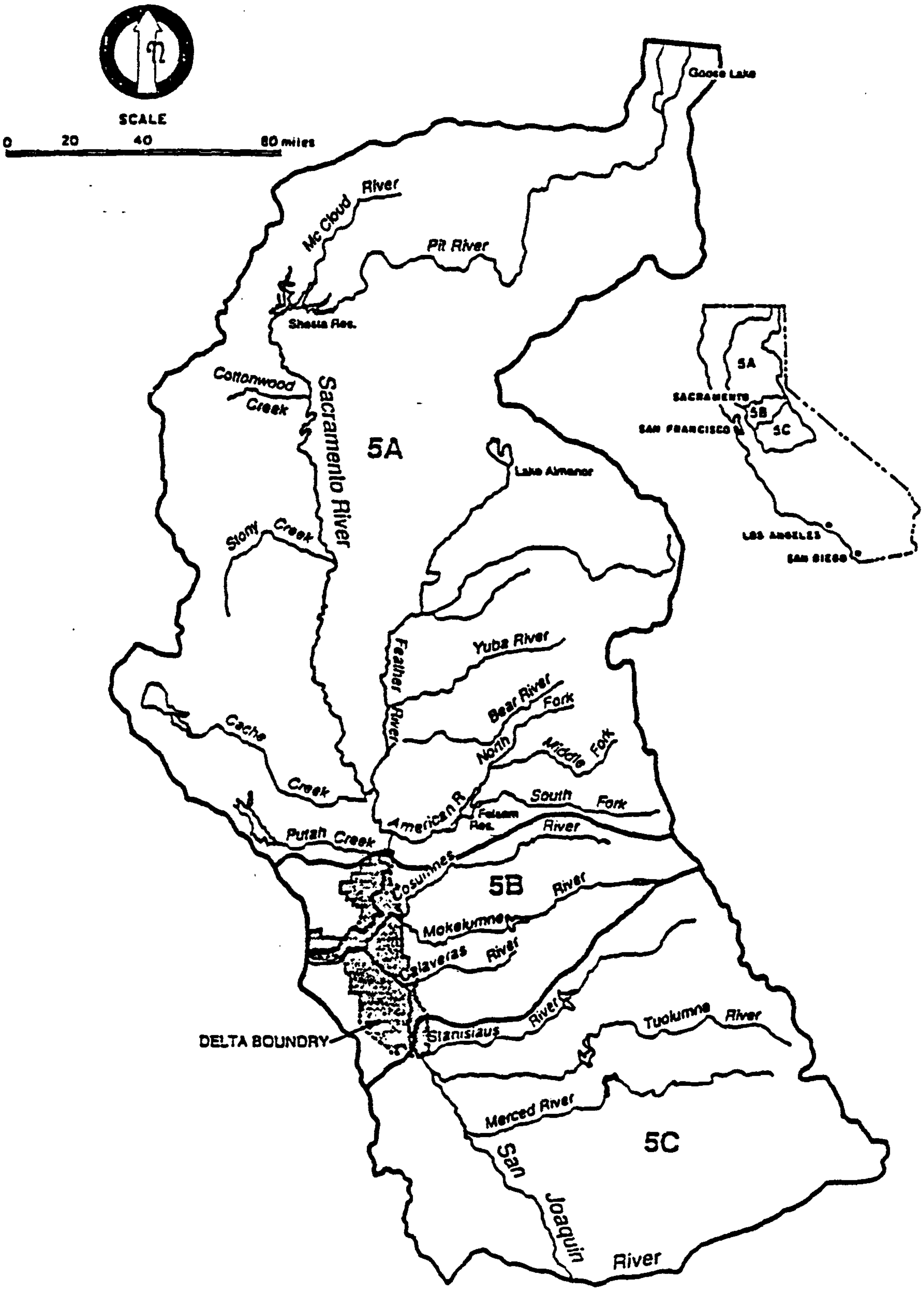


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Table 4

Typical Nutrient Loads to Lakes and Reservoirs

Land Use	*Total P* *(g/m²/yr)*	*Total N* *(g/m²/yr)*
Urban	0.1	0.25
Rural/Agriculture	0.05	0.2
Forest	0.005	0.1
Atmosphere	0.025	1.0

(After Rast and Lee, 1982)

22

D-044216

these tributaries in the summer months.

Another factor that would tend to make the estimated phosphorus loads from land runoff high is the fact that many of the headwaters of these tributaries contain reservoirs. Reservoirs tend to be efficient traps for phosphorus. Ordinarily, on the order of 80% of the phosphorus entering a reservoir is trapped within the reservoir and becomes part of the reservoir sediments. It is therefore likely that a large part of the phosphorus that would be derived from agricultural runoff above the reservoirs would not be transported to the Delta.

In addition to phosphorus contributed to the Delta tributaries from land runoff and domestic wastewater sources, consideration should be given to phosphorus sources within the Delta. There are two principal sources of phosphorus within the Delta. One of these is wastewater discharges to Delta channel waters and the other is drainage from the agricultural lands within the Delta. According to DWR (1989), there are approximately 200,000 people living in the Delta system. If all of the phosphorus in the domestic wastewaters from these people were discharged to the Delta channels, it would represent an insignificant additional source of phosphorus for the Delta. It appears, however, that a very small fraction of the wastewaters associated with this population are discharged to Delta channels that could represent a source of phosphorus for the waters exported from the Delta in the State Water Project. According to Archibald (1991), approximately 14,500 people living within the Delta discharge wastewaters to the Delta. It is therefore concluded that domestic wastewater sources of phosphorus for the Delta are insignificant sources of phosphorus for the Delta.

According to DWR (1989), there are about 520,000 acres of agricultural land within the Delta. These lands are fertilized for agricultural crop production. It would be expected that part of this fertilizer would be present in the agricultural drains from the Delta islands. If it is assumed that the phosphorus export coefficients from the Delta island agricultural activities is 0.1 g P/m^2/yr (a high value for most agriculture), it is found that the Delta island agricultural activities could potentially contribute on the order of 1 x 10^3 kg P/day to Delta channel waters.

Agee (1991) provided the authors with some DWR monitoring data for the phosphorus content of agricultural drains from Empire Island within the Delta. This data covered about 2.5 years of sampling during the period 1987-89. While the phosphorus concentration values in the drainage water were highly variable, the average of the 30 values is 0.13 mg P/L. It is therefore evident that, at least for Empire Island, the amount of phosphorus in the agricultural drainage water is about the same as the phosphorus diverted from the channels to this island. Therefore, since the load of phosphorus exported at the Clifton Court Forebay and discharged from the main stem of the Sacramento River to the San Francisco Bay system is approximately equal to the amount of phosphorus contributed to the Delta at Greene's Landing and Vernalis on the Sacramento and San Joaquin rivers, respectively, and since there are no obvious potentially large sources of phosphorus within the Delta other than agricultural drainage and since the agricultural drainage data does not show high phosphorus content compared to the Delta channel waters, it is concluded that phosphorus sources within the Delta are insignificant compared to phosphorus sources in the tributaries to the Delta.

It is, therefore, evident that the amount of phosphorus contributed from land runoff to the Delta tributaries during the summer months is insignificant compared to the amount of phosphorus derived from domestic wastewater sources which are discharged to the tributaries of the Delta. While these estimates are based on general overall characteristics of the Delta and its tributaries, it is clear that a substantial part of the summer phosphorus load to the Delta could be derived from domestic wastewaters discharged to tributaries of the Delta. These estimates indicate that domestic wastewater sources of phosphorus for the Delta could be a significant part of the total P load. Therefore, it is appropriate to pursue refining the estimates of the potential benefits of controlling phosphorus in domestic wastewaters on algal related water quality problems for water utilities that use Delta water as a raw water source. The authors are in the process of obtaining additional data that could be used for this purpose.

As discussed by Jones and Lee (1986), it is important to evaluate whether at least 25% of the total P load for a particular waterbody is controllable in order to ascertain whether phosphorus control programs would likely produce some benefit in reduced algal biomass. It is now well established that at least this amount of phosphorus must be removed in order to cause a discernible change in algal biomass. It is highly inappropriate to assert, as has been done by those not familiar with the results of eutrophication management programs, that in order to produce an improvement in eutrophication related water quality, it is necessary to reduce the planktonic algal chlorophyll to less than about 5 ug/L. It is well known from actual experience in many waterbodies where phosphorus input control has been practiced that significant benefits in both recreational and domestic water supply water quality have been found whenever on the order of 25% or so of the total available phosphorus load is controlled. The improvements in water quality occur independent of the trophic state (chlorophyll concentration) of the waterbody. The 5 ug/L chlorophyll level value is based solely on improving the algal related water clarity (Secchi depth) for recreational use and has little or nothing to do with domestic water supply raw water quality or, for that matter, many of the other recreational impacts of eutrophication such as the frequency and severity of obnoxious algal blooms that occur in a waterbody.

It is important in making the evaluation of P loads to the Delta to focus on the control of those loads that lead to algal available P in the waterbodies where there is concern about algal impacts on domestic water supply water quality. As discussed by Lee et al. (1980), there are a variety of chemical and biological processes that take place in aquatic systems that convert algal available forms of phosphorus into non-available forms and vice versa. Typically, however, in rivers and in aquatic systems like the Delta the net conversion would likely be toward forms not available to support algal growth. It would therefore be important to conduct in-depth studies of the aqueous environmental chemistry of phosphorus in the tributaries to the Delta, within the Delta, the water export systems from the Delta, and within any off-Delta reservoirs in order to focus the phosphorus control programs on those parts of the phosphorus which are responsible for stimulating algal growth. Well established methodologies are available today to determine algal available phosphorus. For further information on this topic, consult Lee et al. (1980).

An additional source of phosphorus for domestic water supply reservoirs in the central and southern part of the state is the irrigation return water that enters the aqueduct system that transports water to the south and directly into some reservoirs that are part of this system. At this time the authors do not have data on the phosphorus content of the waters entering various reservoirs in the southern part of the state where algal related water quality problems have been found. If such data does not now exist, it should be developed in order to ascertain whether there are significant sources of algal available phosphorus that could stimulate algal growth in reservoirs in the southern part of the state. If significant sources of this type exist, then phosphorus control programs should be considered for these sources. The direct addition of alum to these waters may be a highly cost effective way of removing phosphorus from sources of this type (see Lee, 1973).

According to Means (1991), significant algal populations are found in the aqueduct system transporting Delta waters to the south. As part of developing algal control programs, consideration should be given to the role that algae that develop in the aqueduct play in causing algal related water quality problems to the water utilities that use aqueduct waters as a source.

It is important to understand that the frequently used approaches for estimating whether nitrogen or phosphorus is limiting algal growth in a lake or reservoir are often inappropriate. Attempts to look at total phosphorus/nitrate ratios for estimating nutrient limitations are unreliable for estimating the impact of altering phosphorus loads to a waterbody on the planktonic algal growth that occur within the waterbody. As discussed by Lee and Jones (1981) in an AWWA Quality Control in Reservoirs Committee report, in order for nitrogen or phosphorus to limit the biomass of algae that develops in a waterbody, the concentrations of available forms must be below growth rate limiting concentrations at peak biomass when there is concern about algal related water quality problems. Ratios of nutrients are unreliable predictors of algal limiting nutrients and can readily lead to erroneous conclusions about the potential benefits of controlling nitrogen or phosphorus inputs to a waterbody on reducing algal related water quality problems.

Rast et al. (1983) have shown that even though the growth rate of algae in a waterbody is not controlled by phosphorus, it is possible to use the Vollenweider-OECD modeling relationships described by Jones and Lee (1986) to predict the potential benefits of controlling phosphorus input to a certain degree on the algal related water quality of a waterbody. As discussed by Jones and Lee (1986) and Rast et al. (1983), the Vollenweider-OECD and post-OECD database, which now exceeds over 500 waterbodies located in various parts of the world (see Figure 5), shows that changing the phosphorus load to a waterbody produces in most waterbodies a readily predictable change in the planktonic algal chlorophyll concentration that developed in the summer within the waterbody. This relationship holds even though phosphorus is not an algal growth rate limiting element in the waterbody, i.e., phosphorus is surplus compared to algal needs. This appears to be the case throughout the Delta system and in down-Delta reservoirs.

Figure 5 shows that there is a relationship between the normalized phosphorus loads to a waterbody and the planktonic algal chlorophyll that develops within the waterbody. The normalizing factors are the waterbody's mean depth and hydraulic residence time. The abscissa term in Figure 5 includes L(P) which is equal to the areal annual P load in mg P/m^2/yr) divided by the q_s which is the mean depth divided by the hydraulic residence time (T_w in years) in m/yr. The mean depth of the waterbody is the volume of the waterbody divided by its surface area. The hydraulic residence time is the volume of the waterbody divided by the annual inflow rate. The abscissa normalizing term has been found to be approximately equal to the annual phosphorus concentration in the waterbody. Therefore, the relationship shown in Figure 5, in its most basic terms, is simply a statement of algal stoichiometry in which there is a correlation between the phosphorus concentration in a waterbody and the algal growth that occurs in the waterbody. While this relationship is not applicable to all waterbodies, it is applicable to well over 80% of the world's freshwater waterbodies. Jones and Lee (1986) provide guidance on how to determine its applicability to a particular waterbody.

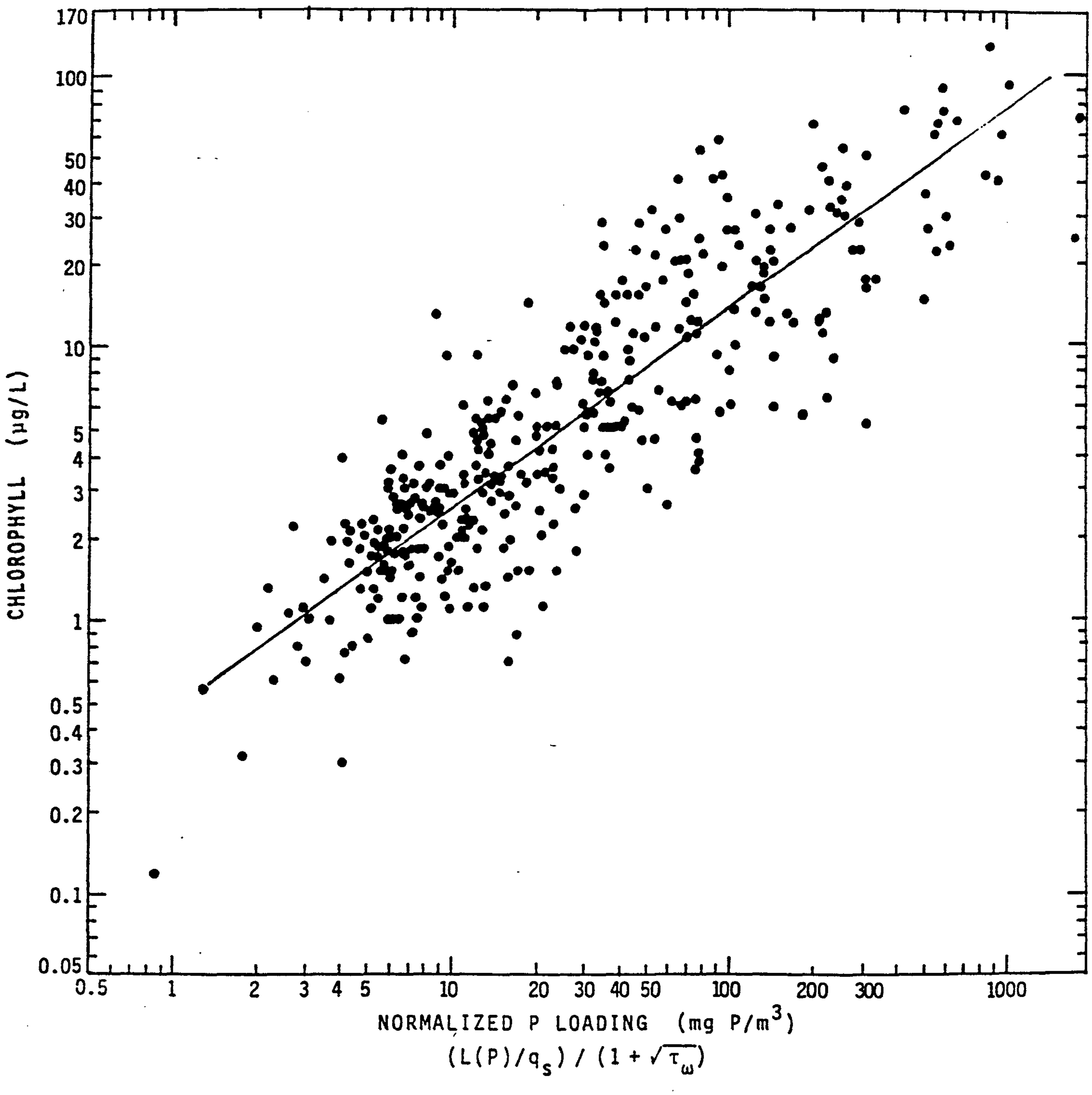
In order for the growth of algae in a waterbody to be proportional to the available phosphorus concentrations in the water, even though phosphorus is not limiting their rate of growth, it is necessary that all other nutrients needed by the algae be present in surplus amounts compared to algal needs. The chemical of typical concern in this regard is nitrogen in the form of nitrate and/or ammonia. The DWR monitoring data for the Delta waters shows that nitrogen is not limiting algal growth in these waters. Further, since algal growth in the Delta is about equal to what is predicted based on phosphorus chlorophyll relationships for waterbodies located throughout the world, it appears that all other elements needed for algal growth are present in sufficient concentrations to allow growth to the extent possible based on the characteristics of the Delta and the phosphorus loads.

From the information available at this time, it appears that phosphorus should be added to the list of contaminants of Delta system waters that should be investigated for the possible development of control programs. There is a potential for such programs to significantly improve the algal related tastes and odors and other domestic water supply water quality problems, including THM precursor formation, through phosphorus control in the Delta system and its tributaries. Such control programs could affect domestic water supply water quality for many millions of people in California.

Figure 5

Relationship between Normalized P Loading and Chlorophyll in Lakes and Reservoirs World-Wide

After Jones and Lee, (1986)



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One of the potential consequences of phosphorus control for tributaries of the Delta and in the Delta is the decreased fish production within the Delta. Jones and Lee (1986) have reported a strong, highly significant relationship between the phosphorus loads to waterbodies located in various parts of the world and the fish production within these waterbodies (see Figure 6). Basically, the relationship is one of increased primary production (algae) in lakes and reservoirs resulting in increased secondary (zooplankton) and tertiary (fish) production. Since the primary productivity and algal biomass in many lakes and reservoirs, as well as other waterbodies, is correlated with the phosphorus concentration within the waterbody and since phosphorus concentrations within the waterbody can be correlated with phosphorus loads when normalized by the waterbodies' hydrological and morphological characteristics, it is not surprising that a relationship is found between normalized phosphorus loads in lakes and reservoirs located in various parts of the world and fish production. Therefore, decreasing the phosphorus loads to the Delta will likely decrease the fish production within the Delta.

Using the relationship developed by Jones and Lee (1986), between normalized phosphorus loads and fish production, it is found that in the range of planktonic algal chlorophylls of concern within the Delta system that a 50% reduction in the phosphorus load to the Delta would be expected to decrease fish production by 40 to 60% dependent upon the planktonic algal chlorophyll concentration. While there may be some who assert that decreasing phosphorus loads to the Delta system should not be practiced because of the adverse effects on the fisheries of the Delta, it is clear that the problems of the fisheries of the Delta are not fish food supply related and therefore controlling phosphorus inputs will likely have little or no impact on fish production for the fish species of primary concern in the Delta, such as striped bass. Phosphorus control, however, will almost certainly have an impact on the rough fish population, such as carp.

It is, therefore, concluded that because of the importance of the Delta as a water supply source for two-thirds of the population of California that a much greater effort should be devoted to source water quality control for contaminants that either directly or indirectly, as in the case of phosphorus, cause significant water quality problems for water utilities that use Delta waters as a source of supply. Understanding the specific sources of various contaminants and investigating the potential for control of these contaminants at the source could be significantly beneficial in improving domestic water supply water quality for many of the people in California.

Management of Eutrophication

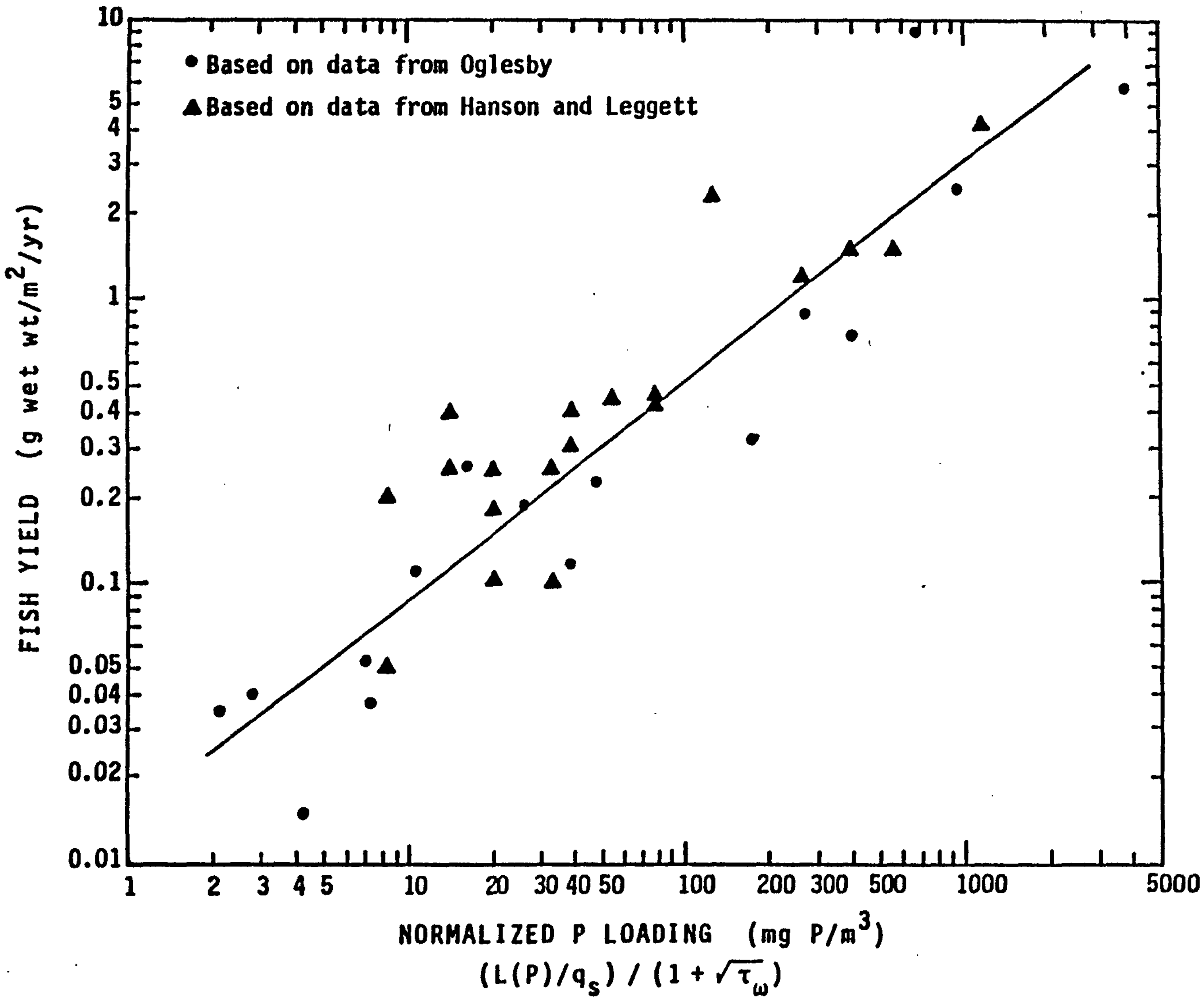
Lee and Jones, through their activities in the AWWA Quality Control in Reservoirs Committee, developed a report that was reviewed and approved by the committee which serves as a guide to water utilities on the approaches that should be considered in evaluating whether phosphorus control from watershed sources could be a potential benefit in improving a water utility's domestic water supply raw water quality. Additional information on this topic is provided by Lee and Jones (1984a, 1988b) and Jones and Lee (1986). An example of the application of the evaluation of the potential benefits in controlling phosphorus loads to a domestic water supply reservoir is provided for Lake Ray Hubbard, a city of Dallas, Texas water supply reservoir, by Archibald and Lee (1981).

There are a variety of techniques that have been used with success in some locations for management of eutrophication of waterbodies. Generally, the utility of these approaches has been judged based on improvement of recreational uses of the water. Thus far, inadequate attention has been given to the improvement of domestic water supply raw water quality. A review of the various techniques that have been used for managing eutrophication has been published by Lee (1973) and by Cooke et al. (1986).

Figure 6

Relationship between Normalized P Loading and Fish Yield

After Jones and Lee, (1986)



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While there are several techniques, such as aeration, dredging, manipulation of fish and other aquatic organism populations, aquatic weed harvesting, etc., that have been used with some success for managing eutrophication related recreational impacts in lakes and reservoirs, it is questionable whether many of these techniques have applicability to significantly improving domestic water supply eutrophication related water quality. For example, one of the techniques that is often said to be beneficial for managing eutrophication related water quality in lakes and reservoirs is aeration-destratification of the waterbody. This technique, however, does not necessarily improve eutrophication related water quality for recreational and domestic water supply uses.

The value of aeration of reservoirs in improving domestic water supply water quality was reviewed by the AWWA Quality Control in Reservoirs Committee. This committee reported that after extensive review of the data available, there were serious questions as to whether aeration of a water supply reservoir would improve water quality. It was found that in some water supply reservoirs, aeration caused greater algal related water quality problems than occurred in the unaerated reservoirs. This situation is to be expected in stratified reservoirs where the thermocline serves as an effective barrier to nutrient regeneration and transport from the deeper waters of the lake to the surface waters where the algae develop. The aeration-destratification of a water supply reservoir, however, should be evaluated cautiously. It appears that in some instances, but not all, there are benefits in domestic water supply water quality associated with aeration-destratification of the waterbody. As discussed by Lee (1973), hypolimnetic aeration of reservoirs in which destratification does not occur has been found to be an effective method of improving the domestic water supply water quality of hypolimnetic waters.

It is important for water utilities that are facing eutrophication related water quality problems to focus their efforts to the greatest extent possible on controlling algal nutrients. Efforts to control eutrophication by other methods must be carefully evaluated.

Control of Hazardous and Other Chemicals

Typically, water utilities and regulatory agencies conduct fairly effective programs for control of hazardous contaminants, such as heavy metals, pesticides, etc., that can cause significant water quality problems in domestic water supply. Usually, such problems are detected through the routine monitoring that is done by the utility and regulatory agencies. When excessive concentrations of a contaminant are found, it is usually relatively straightforward to develop control programs for that contaminant from the particular source(s). It is important to point out, however, that the routine monitoring programs that are typically conducted by water utilities and regulatory agencies measure only a small number of the potentially significant chemicals that can be present in an urbanized-industrialized watershed. While water pollution, air pollution, and solid and hazardous waste management programs are becoming more effective in controlling the discharge of known, highly hazardous chemicals, such as the priority pollutants, water utilities should go beyond the routine monitoring to critically evaluate whether there are other sources of chemicals in their watershed that could degrade domestic water supply water quality. Basically, water utilities should become highly pro-active toward protection of their water supply sources from all chemicals that could be adverse to providing a potable and palatable water.

Groundwater Quality Protection

Many water utilities, especially in California, have all or parts of their domestic water supply based on groundwater sources. Some communities, such as Pittsburg, California, even though they have 100% of their normal domestic supply provided by surface water sources, have installed standby well(s) as an emergency supply during drought or other conditions which would interrupt the surface supply source. The current drought has emphasized the importance of a highly developed, coordinated conjunctive use program in the state of California, where during wet years, surplus surface water is recharged into groundwater basins. This recharged water would then be available for use during future droughts. This drought has also pointed to the extreme importance of protecting groundwater and groundwater aquifer quality. For many years, the state of California has had regulations which prohibit activities that can lead to groundwater pollution. It is the experience of the authors, however, that over the years, including today, these regulations are not being adequately implemented with the result that groundwater pollution is still occurring at a significant rate in various parts of the state. In many cases, such as those associated with municipal and some industrial solid waste disposal by land burial, the groundwater pollution is not only destroying the use of the water for domestic and some other purposes, but is also destroying the use of parts of the aquifer for conjunctive use storage. It is therefore important that every possible step be taken to protect groundwater aquifer systems from immediate as well as long-term pollution.

One of the most potentially significant sources of groundwater pollution for waters that could be used for domestic water supply purposes is by municipal landfill leachate. US EPA estimates that there are on the order of 75,000 landfills in the US with over 75% of them polluting groundwaters at this time. In California, the regional and State Water Resources Control Boards as part of their Solid Waste Assessment Test Annual Report to the legislature concluded that of the approximately 300 landfills in the state investigated thus far, over 80% of them are polluting groundwaters. While existing groundwater pollution by municipal and industrial landfills is occurring from unlined landfills, the clay and membrane lined landfills of the type being constructed today ("dry tombs") are widely recognized as simply postponing the problems of groundwater pollution by landfill leachate. Ultimately, as discussed by Lee and Jones (1991), the landfill cover will fail to keep moisture out of the landfill and the landfill liners will fail to keep leachate from polluting groundwaters.

Table 5 presents information on the typical composition of municipal landfill leachate for the common contaminants. Typically municipal landfill leachate must be diluted at least a thousand-fold and more commonly over ten-thousand-fold before groundwaters contaminated by such leachate would be considered to comply with drinking water standards (MCL's) from known leachate constituents. Since very limited dilution of contaminants occurs in groundwater, it is evident that municipal landfill leachate represents a highly significant threat to domestic water supply water quality. The US EPA (1988) has determined that when a groundwater well is contaminated by municipal landfill leachate that it is appropriate to assume that the well has to be abandoned and a new well be constructed in a different aquifer or at a sufficiently distant location so that it will not intercept any groundwaters contaminated by leachate. This situation arises from the fact that contaminants in municipal landfill leachate are of such a nature as to make it impossible to be removed from the aquifer to a sufficient degree to render the aquifer waters usable for domestic purposes. While in many parts of the country construction of new wells to replace those that have been contaminated by leachate is feasible, in the more arid areas and ultimately everywhere this approach cannot be followed since there is a finite amount of groundwater available that can be used for domestic water supply purposes.

It is important to understand the difference between the pollution of domestic water supply groundwaters by VOC's, such as TCE, and by municipal landfill leachate. While it is relatively easy to remove many of the VOC's from contaminated groundwaters and produce a water that is considered suitable for domestic consumption, it is extremely difficult if not impossible to treat a groundwater contaminated by municipal landfill leachate to the degree necessary so that it would be considered appropriate for domestic water supply use. Municipal landfill leachate contains a wide variety of contaminants which are highly difficult to remove. Further, because of the large amounts of uncharacterized, unknown, non-conventional contaminants in landfill leachate, using treated groundwaters for domestic water supplies that have been contaminated by municipal landfill leachate will always be a threat to public health since it will never be possible to be certain that the treatment has removed all

Table 5

Concentration Ranges for Components of Municipal Landfill Leachate

Parameter	"Typical" Concentration Range	"Average"*
BOD_5	1,000 - 30,000	10,500
COD	1,000 - 50,000	15,000
TOC	700 - 10,000	3,500
Total volatile acids (as acetic acid)	70 - 28,000	—
Total Kjeldahl Nitrogen (as N)	10 - 500	500
Nitrate (as N)	0.1 - 10	4
Ammonia (as N)	100 - 400	300
Total Phosphate (PO_4)	0.5 - 50	30
Orthophosphate (PO_4)	1 - 60	22
Total alkalinity (as $CaCO_3$)	500 - 10,000	3600
Total hardness (as $CaCO_3$)	500 - 10,000	4200
Total solids	3,000 - 50,000	16,000
Total dissolved solids	1,000 - 20,000	11,000
Specific conductance (umhos/cm)	2,000 - 8,000	6,700
pH	5 - 7.5	63
Calcium	100 - 3,000	1,000
Magnesium	30 - 500	700
Sodium	200 - 1,500	700
Chloride	100 - 2,000	980
Sulfate	10 - 1,000	380
Chromium (total)	0.05 - 1	0.9
Cadmium	0.001 - 0.1	0.05
Copper	0.02 - 1	0.5
Lead	0.1 - 1	0.5
Nickel	0.1 - 1	1.2
Iron	10 - 1,000	430
Zinc	0.5 - 30	21
Methane gas	60%	
Carbon dioxide	40%	

All values mg/l except as noted

After: Lee et al. (1986)
* From CH2M Hill based on 83 Landfills (1989)

hazardous chemicals.

Another consequence of contaminating groundwaters by municipal landfill leachate which is of major significance to some water utilities is the loss of aquifer storage capacity as part of conjunctive use of surface and groundwaters. Those parts of aquifers that have been contaminated by municipal landfill leachate cannot be used for domestic water supply conjunctive use even though attempts are made to try to flush out the residual contaminants in the aquifer. It is therefore apparent that domestic water supply utilities and, for that matter, individual homeowners who depend on groundwaters near a municipal landfill must be highly concerned about the potential for groundwater contamination by landfill leachate.

Presented below is a suggested set of actions that municipal water agencies and water districts should take to protect the quality of existing and potential groundwater water supply sources from landfill contamination.

1. Determine if existing and previously closed sanitary landfills or other waste management units are contaminating groundwaters.

Any groundwater contamination by municipal landfill leachate, independent of whether it causes a drinking water standard to be exceeded, should be considered to be a serious threat to public health and domestic water supply water quality. Generally, state water pollution control agencies are requiring that all landfill owner/operators establish groundwater monitoring programs for active as well as closed landfills. Water utilities should periodically review the state and/or local agency files to determine the adequacy of the groundwater monitoring programs that have been established for the landfills located in their aquifer recharge area. This should be done by an individual on the utility's staff or a consultant who is highly familiar with groundwater quality monitoring near landfills.

It is the authors' experience that typically the groundwater monitoring programs that are being required by state agencies for existing, much less previously closed, landfills are inadequate to define with a high degree of certainty whether pollution of groundwater is occurring and the degree and extent of pollution. It may be necessary for the utility to request and, if necessary, take legal action, to require that the state and/or local agency responsible for groundwater quality protection will require that the owner/operator of existing as well as previously closed landfills establish an adequate groundwater monitoring program for each landfill that could contaminate the utility's aquifer. It is suggested that the groundwater monitoring programs be designed so that they would have at least a 95% probability of detecting groundwater pollution by landfill leachate. As discussed by Lee and Jones (1991), this will require a much more extensive groundwater monitoring program than is typically being developed today for landfills.

2. If contamination of an aquifer that is or could be used for domestic water supply purposes has occurred, require that the owner/operator of the landfill define the areal extent and degree of groundwater contamination by the landfill.

The determination of the extent and degree of groundwater contamination by a landfill will require that an extensive set of monitoring wells, typically nested to sample water at various depths at various locations, be used. These wells should be sampled at no less than quarterly intervals over one year to define the degree and extent of contamination that has occurred. Normally, such a sampling program has to be conducted in phases where at the end of the first phase, when it becomes clear that insufficient information is available to fully define the extent and degree of contamination, that additional monitoring wells will have to be constructed and sampled.

3. Require that the landfill owner/operator initiate comprehensive groundwater quality remediation programs to try to remove **all** contamination from the groundwater and the aquifer.

Work on remediation of Superfund sites is now showing that groundwater remediation from simple contamination, such as from VOC's, is difficult to achieve. It is clear now that typically it will take many tens of years of continuous pumping of the contaminated water in order to stop the spread of the contamination and to reduce the degree of contamination to the maximum extent possible. It is becoming recognized that for some types of contaminants it may not be possible to achieve background concentrations. The owner/operator of the landfill, however, should be required to aggressively pursue a remediation program to achieve background concentrations of contaminants to the maximum extent possible.

4. If the owner/operator of an active landfill cannot prevent further contamination from the landfill, the owner/operator should stop accepting wastes and close the landfill. If closure does not stop groundwater contamination, require that the waste be exhumed and properly treated, and the residues be deposited at a suitable location where groundwater pollution will not occur.

It has become clear that in many instances the only way to truly protect a domestic groundwater supply from municipal landfill leachate contamination is to exhume the wastes. This will be especially true for those landfills that are located in areas where moisture can enter the landfill from groundwaters. In situations where the only source of moisture for leachate generation is through the cap, it may be possible to stop further groundwater pollution by leachate generated in the landfill by construction of a cap that will, in fact, prevent moisture from entering the landfill. It is important to note that the typical landfill caps that are being constructed today are inadequate to prevent leachate generation within the landfill and will not achieve this objective. Further, the owner/operator of a landfill that is capped as a means of attempting to prevent groundwater contamination must be required to maintain the cap for as long as the wastes are present (forever) in order to prevent moisture from entering the landfill. It is felt that any owner/operator that fails to provide this type of maintenance of the cap must be required to exhume the wastes.

5. For all landfills that could effect a domestic groundwater supply, the water utility should require that all groundwater quality monitoring data on the landfill be sent to the utility for the utility's review and comment at the time that it is submitted by the landfill owner/operator to the regulatory agencies.

For existing as well as closed landfills, water utilities should take a pro-active approach to groundwater quality protection where they have specific staff members or consultants who will review all routine groundwater monitoring data as it is submitted to the agency by the owner/operator of the landfill. The authors have seen situations where the regulatory agency personnel do not have time or do not appreciate the significance of the potential damage that municipal landfill leachate can cause to a groundwater based domestic water supply. They also may not understand the importance of detecting leakage from a landfill at the earliest possible time. It is therefore imperative that the water utilities conduct their own independent data review of the groundwater quality monitoring program at all active as well as closed landfills that could contaminate the aquifer.

6. Water utilities should require that all owners/operators of landfills that could impact existing or potential domestic water supplies maintain the leachate removal system, the groundwater monitoring system, the landfill cap, and all groundwater diversion systems **FOREVER.**

Water utilities should review the financial assurance instruments that are submitted by owners/operators of landfills that are designed to provide for post-closure monitoring and maintenance of the landfill. At this time, in some states, no financial assurance is required for municipal landfill post-closure operations. In others, such as California, the financial instruments used by owners/operators of landfills are grossly inadequate to provide the amount of funds necessary to provide for required post-closure care activities that will prevent the landfill from polluting groundwaters at any time in the future. Water utilities should aggressively work toward requiring that the owner/operator of the landfill and the regulatory agencies establish a trust fund that will ensure that adequate funds are available to carry out these activities **FOREVER.**

For active landfills, the trust fund can be developed from disposal fees. For previously closed municipal landfills that could contaminate a domestic water supply, the utilities should work through the state and local agencies and, if necessary, the courts to require the principle responsible parties who owned/operated the landfill, as well as the public that contributed waste to the landfill, to develop a trust fund of sufficient magnitude to ensure that the landfill will be properly closed and maintained **FOREVER.** The magnitude of the trust fund should be sufficient to cover not only the post-closure monitoring and maintenance but also the costs to exhume the wastes, properly treat them, and rebury the non-recyclable, non-reusable residues at an appropriate location that will not contaminate groundwaters in the future.

7. Water utilities should aggressively pursue developing approaches for the management of solid waste in their groundwater supply watersheds that will minimize the potential for groundwater quality problems at any time in the future. They should oppose the "dry tomb" approach for municipal solid waste management in areas where domestic water supplies could be contaminated because of the high probability that that approach will ultimately lead to groundwater contamination.

It is suggested that it would be appropriate for water utilities to require that the owner/operator of existing as well as proposed landfills provide a detailed discussion of the plausible worst case scenarios that could occur at the landfill that could lead to groundwater pollution. The reports made by consulting firms working on behalf of governmental agencies and/or landfill owners/operators in the environmental impact statements (EIS's) or in California environmental impact reports (EIR's) typically do not properly assess the potential for groundwater pollution by landfills. During the past couple of years the authors have frequently observed consulting firms working on behalf of the applicant for a landfill make such statements as "since the landfill is lined, there can be no water pollution." Another example is that "any leakage of leachate from the landfill will be detected by the groundwater monitoring system. Once detected, remediation programs will be initiated which will clean up the groundwaters." Such statements are not an appropriate assessment of the current understanding of the ability of landfill liners to prevent groundwater pollution and groundwater monitoring systems to detect it once it has occurred. Further, as discussed above, it is not possible to completely clean up an aquifer contaminated by municipal landfill leachate.

As part of evaluating the worst case scenario(s) for groundwater pollution by a landfill, the owner/operator of a landfill should be required to provide detailed discussion of how they will prevent groundwater pollution at a particular landfill based on worst case scenario conditions. They should also provide detailed discussions with associated cost estimates of what remediation steps they will take to remediate the groundwaters that are polluted by landfill leachate. The worst case scenario should consider that the proposed groundwater monitoring program will fail to detect groundwater pollution. It should be assumed that a pollution plume has occurred for considerable distances downgradient where it is detected in production wells used for domestic water supply or other purposes.

One of the best ways for water utilities to protect their groundwater supplies from pollution by new landfills is to develop a highly aggressive program of work toward developing alternative methods of managing municipal solid and industrial wastes so that they are not buried in "dry tombs" where they can ultimately pollute groundwater. It is clear that the "dry tomb" approach is not a viable approach for municipal solid waste management in most parts of the US. Alternative approaches are available. While initially more expensive compared to what the public has become used to paying for municipal solid waste disposal, in the long-term they will be less expensive and provide for true long-term groundwater quality protection. For additional information on the potential significance of pollution of groundwaters by municipal landfill leachate, consult Lee and Jones (1984b, 1991).

While the focus of this groundwater quality protection program is municipal landfills, similar kinds of programs should be directed toward all waste management units, such as wastewater lagoons, as well as agricultural uses of chemicals. Further, utilities with groundwater supplies near saline waters, such as along the coast, should be determining whether saltwater intrusion is occurring to a significant extent that could ultimately pollute the groundwaters of the region.

It is the experience of the authors that inadequate attention is being given to the potential for groundwater contamination by chemicals in surface waters that are deliberately recharged or that naturally recharge aquifers. Water utilities should be conducting intensive monitoring programs of all recharged waters to ensure that such waters do not contain contaminants that will pollute the aquifer.

Conclusions

It is evident that there are a number of ways in which municipal water agencies-utilities and regulatory agencies can improve domestic water supply raw water quality by implementing pollutant control programs at the source. It is well known that eutrophication related water quality problems are controllable through the use of algicides, such as copper sulfate, or through reductions in the amount of aquatic plant nutrients, especially phosphorus, entering a lake or reservoir.

Municipal water utilities should be evaluating the activities that take place in the domestic water supply watershed that could be adverse to their raw water quality. In addition to problems associated with algal growth and the limitation of phosphorus inputs to lakes and reservoirs, water utility watershed activity, concern should be focused on evaluating potential sources of all chemicals and microbial contamination that could cause water supply water quality problems. While water utilities have a long history of aggressively pursuing the control of industrially and agriculturally derived contaminants, such as phenols, toxic chemicals, pesticides, etc., in general, water utilities have not been sufficiently aggressive in controlling nutrients that lead to excessive fertilization related water supply water quality problems.

With increased attention being given to control of THM's in treated waters, emphasis should be placed on understanding the sources of organic THM precursors. A significant effort should be made to develop THM precursor land use export coefficients. Each water utility should determine the dominant sources of THM precursors in its watershed and evaluate on a site-specific basis the potential for control of the most significant sources. THM precursor control programs should be initiated in those situations where the collective development of such a control program would result in a significant lowering of the THM's produced upon disinfection of the water supply.

Those water utilities that have significant sources of bromide within their watershed should aggressively pursue controlling the bromide at its source in order to prevent, or at least minimize, brominated THM formation.

Water utilities utilizing groundwaters as all or part of their supply, at this time or potentially in the future, should adopt a highly pro-active program of groundwater quality protection from municipal and industrial landfills, waste treatment lagoons, agricultural chemical use, subdivisions employing septic tank wastewater disposal systems, etc. Included within this program should be a careful monitoring of the quality of all waters that are recharged to groundwater as part of a conjunctive use program as well as recharge that occurs naturally. This program should be designed to prevent further groundwater pollution which would not only destroy the use of groundwaters for domestic purposes, but would also impair the use of the aquifer for conjunctive use storage.

Municipal water utilities and agencies that use the Sacramento-San Joaquin River Delta as a water supply source should investigate the potential benefits of the control of phosphorus in domestic wastewater

D-044229

sources discharged to tributaries of the Delta. It has been found that during the summer months, domestic wastewater sources are the primary source of phosphorus for the Delta system. Phosphorus control from these sources with readily available, widely practiced technology could result in a significant reduction of algal growth within the Delta and in down-Delta reservoirs as well as in the aqueduct system. Such reduced growth could significantly reduce the algal related taste and odor problems as well as algal derived THM precursors.

The algal related taste and odor problems that have begun to occur in Lake Tahoe appear to be related to increased planktonic algal growth in the open waters of the lake and especially increased periphyton (attached algal) growth in the nearshore waters. These increased growths are related to increased nitrogen input to the lake from atmospheric sources and nitrogen and phosphorus input to the nearshore waters of the lake due to groundwater transport of fertilizers used for lawn and shrubbery fertilization. In order to reduce the frequency and severity of algal related domestic water supply water quality problems in Lake Tahoe, it will be necessary to significantly curtail the use of automobiles and other vehicles powered by internal combustion engines in the Lake Tahoe watershed and to ban the use of lawn fertilizers and lawns within the lake's watershed.

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D-044232

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One of the principle areas of activities of Drs. Lee and Jones has been domestic water supply water source water quality management. This is an area of activity that Dr. Lee has worked on for over 30 years. Drs. Lee and Jones were Chairman and Co-Chairman, respectively, of the American Water Works Association Quality Control in Reservoirs Committee. They have served as advisors to many municipal water utilities, state and federal agencies, other countries, and international agencies in various aspects of water quality management.

RECENT PUBLICATIONS OF G. FRED LEE and ANNE JONES-LEE

Listed below are several of the recent publications and reports prepared by Drs. G. Fred Lee and Anne Jones-Lee. The publications listed below represent recent discussions of issues in the areas in which they are active as advisors to governmental agencies, industry, and others. A copy of these publications may be obtained upon request. Also, a list of all of their publications on these and other topics is available upon request.

Water Quality Criteria, Standards-Objectives, and NPDES Discharge Limits

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